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ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT
7 RUE ANCELLE, 92200 NEUILLY-SUR-SEINE, FRANCE

AGARD CONFERENCE PROCEEDINGS 588

Selection and Training Advances in Aviation

(les Progrès réalisés en sélection et formation des personnels navigants)

Papers presented at the Aerospace Medical Panel Symposium held in Prague, Czech Republic, in May 1996.

NORTH ATLANTIC TREATY ORGANIZATION

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North Atlantic Treaty Organization
Organisation du Traité de l'Atlantique Nord

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— Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;

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Selection and Training Advances in Aviation

(AGARD CP-588)

Executive Summary

The Aerospace Medical Panel (AMP) of the Advisory Group for Aerospace Research and Development (AGARD) held a Symposium entitled "Selection and Training Advances in Aviation". The AMP Symposium was held to address the effectiveness and utility of current selection and training systems, to describe current research and development in selection and training, to explore potential improvements in operational and experimental systems, and to discuss challenges in future research and development. The Symposium highlighted the outstanding advances being made by many nations in designing, developing, and demonstrating selection and training systems.

The Symposium addressed a number of topics that will benefit both the military and civilian organizations. These benefits include:

- new directions in medical/physiological screening for pilot candidates;
- incorporation of personality and psychomotor measurement in selection systems;
- indications that g-tolerance may be a useful selection criterion for pilot candidates;
- advances in accommodation of various body sizes in the cockpit;
- utility of simulator selection systems;
- validity of intelligence and cognitive abilities tests;
- new methods of integrating decision-making models into crew resource management training;
- insights on the appropriateness and effectiveness of aerospace physiology training;
- consideration that early exposure to effects of spatial disorientation may prevent serious mishaps.

The requirement of accomplishing more with fewer resources challenges researchers to develop study designs and the appropriate measures to evaluate the operational, practical utility of the improved selection and training systems.

Les progrès réalisés en sélection et formation des personnels navigants

(AGARD CP-588)

Synthèse

Le Panel de Médecine Aérospatiale de l'AGARD (AMP) a organisé un symposium sur "les Progrès Réalisés en Sélection et Formation des Personnels Navigants". Ce symposium AMP a eu pour objectif d'évaluer l'efficacité et l'utilité des systèmes de sélection et d'entraînement actuels, de présenter les travaux de recherche et développement en cours dans ce domaine, d'analyser les améliorations susceptibles d'être apportées aux systèmes courants, et de considérer les défis à relever à l'avenir. Le symposium a mis en évidence les progrès exceptionnels réalisés par un certain nombre de pays en ce qui concerne la conception, le développement, et la démonstration des systèmes de sélection et d'entraînement.

Le symposium a examiné un certain nombre de sujets susceptibles d'intéresser des organisations civiles et militaires, à savoir :

— les nouvelles orientations pour l'échantillonnage médical/physiologique des candidats à la formation aéronautique;
— l'incorporation de l'évaluation de la personnalité et de tests psychomoteurs dans les systèmes de sélection;
— les indications selon lesquelles la tolérance à l'accélération de la pesanteur peut être un critère de sélection intéressant pour les futurs pilotes;
— les améliorations en ce qui concerne l'adaptation du poste de pilotage aux morphologies des équipages;
— l'utilité des systèmes de sélection incorporant des séances de simulateur;
— l'intérêt des tests des facultés intellectuelles et cognitives;
— les nouvelles méthodes pour l'intégration des modèles d'aide à la décision dans la formation des équipages à la gestion des moyens;
— les éventuels éclairements sur l'opportunité et l'utilité de la formation physiologique aérospatiale;
— la considération que l'exposition aux effets de la désorientation spatiale dès leur apparition permettrait d'éviter des accidents graves.

La consigne "faire plus avec moins" met les chercheurs au défi de développer des études, ainsi que des mesures appropriées qui permettraient d'évaluer l'utilité pratique et opérationnelle des systèmes de sélection et de formation améliorés.

Contents

† Not available at time of printing.

† Not available at time of printing.

SESSION VIII: FACILITY ADVANCES

POSTERS PRESENTATIONS

Preface

Over the last few decades, aircraft and air operations have become more sophisticated. Technological innovations have resulted in higher-performance, more-complex weapons systems. That increased performance and complexity have placed greater physical and psychological demands upon aviators. Refinement of material and improvements in selection and training technologies have enabled aviator selection and training processes to evolve. The purpose of this Symposium was to unite military and civilian experts in the field of selection and training. The delegates were physiologists, psychologists, flight surgeons and pilots. The scope of the Symposium was very wide. Selection issues included, but were not limited to, body size, intelligence, and physiological responses to high-g environments. Training issues ranged from simulator fidelity to aerospace physiology course requirements. The Symposium participants addressed the effectiveness of current selection and training systems, discussed current research and development in the area of selection and training, and investigated potential areas for improvement.

Topics addressed pertaining to aviator selection and training include:

- human abilities measurement;
- anthropometric accommodation;
- gender differences;
- crew resource management;
- flight simulators;
- spatial disorientation;
- cost effectiveness;
- centrifuge training;
- g-tolerance.

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TECHNICAL EVALUATION REPORT

by

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1. INTRODUCTION

The Aerospace Medical Panel (AMP) held a Symposium on *Selection and Training Advances in Aviation* at the Ministry of Defense, Prague, Czech Republic, 27-31 May 1996. There were 31 papers, 6 posters, and 1 Keynote Address presented at the Symposium. Eight NATO countries, the Czech Republic, the Ukraine, and Argentina contributed papers, and there were 182 delegates in attendance.

2. THEME

Aircraft and air operations have changed significantly in the last few decades in terms of performance, complexity, and the physical and psychological demands placed upon aviators. Aviator selection and training processes have also evolved, not only as a result of these changes but also as a result of advances in available technologies for selection and training. At the same time, knowledge of physiological and psychological processes has moved forward, and understanding of the effectiveness of various training techniques has improved.

This symposium was designed to provide a description and analysis of the effectiveness of current selection and training systems, to describe ongoing research and development in selection and training, and to explore potential areas for improvement in both current systems and future research and development.

3. PURPOSE AND SCOPE

Military Services have never had the problem of too few people wanting to be aviators. The idea of manned flight has always excited the imagination of a great many people, and military aviation in particular projects the image of an exciting, glamorous (and dangerous) career. Experience has taught, however, that not everyone has the physiological or psychological abilities required of an aviator; at the same time, even among those with the necessary minimum abilities, some will prove to be far more effective than others. Therefore, every nation has some type of selection system designed to identify those candidates who are likely to be the best.

Meanwhile, training has progressed from the days when a typical training program consisted entirely of practicing in the airplane with an instructor; now, we have a very expensive combination of academic study, simulator training, and actual aircraft training. As the costs of operating military aircraft have increased tremendously (at a time when many nations' military budgets for flying those aircraft have decreased), the requirement to find more affordable--yet still effective--training techniques has demanded attention.

Thus, the purpose of this Symposium was to bring together military and civilian experts in selection and training--physiologists, psychologists, flight surgeons, and pilots, both military and civilian--to describe current systems and research and to suggest promising new areas for investigation. The scope of the Symposium was very wide: Selection issues ranged from body size through traditional psychological and psychomotor abilities measurement to issues of *g*-tolerance and susceptibility to motion sickness and spatial disorientation. Similarly, training issues ranged from the requirement for in-depth task analyses through simulator effectiveness studies to issues of training for decision-making and crew resource management.

4. SYMPOSIUM PROGRAM

The Symposium began with a Keynote Address that reviewed the history of fighter pilot selection and training, noting changes in those systems resulting from changes in aircraft capabilities as well as changes in external environmental pressures (for example, the beginnings of World Wars I and II). Following the Keynote Address, there were eight Technical Sessions and a Poster Display Session. In order, the Technical Sessions were:

a. Session I, Selection Process Overview
Chairperson: Dr A.J.F. MacMillan, UK

b. Session II, Selection Criteria -- Anthropometric and Female Aircrew
Chairpersons: Dr A.J.F. MacMillan, UK and
Dr S. Hart, US

c. Session III, Current Selection Standards and Future Developments
Chairpersons: Ms J. Davies, UK and
Med Col I. Biesemans, BE

d. Session IV, Advances in Selection Techniques
Chairpersons: Maj H.J. O'Neill, CA and
Maj E. Schroeder, DE

e. Session V, Training Process Overview
Chairperson: Ms J. Davies, UK

f. Session VI, Crew Resource Management, Design Issues and Training Analysis Techniques
Chairpersons: Dr S. Hart, US and
Ms J. Davies, UK

g. Session VII, Physiological Training
Chairpersons: Dr A.J.F. MacMillan, UK and
Maj H.J. O'Neill, CA

h. Session VIII, Facility Advances
Chairpersons: Maj E. Schroeder, DE and
Med Col I. Biesemans, BE

5. TECHNICAL EVALUATION REPORT

5.1 Keynote Address

Wing Commander Cope, in his keynote address, rejected the hypothesis that fighter pilots of past generations would not have been up to the task of flying today's highly complex, technologically sophisticated aircraft in extremely demanding environments. As Cope reviewed the history of powered flight, he provided numerous examples of pilots' continuous adjustment to the increasing capabilities of aircraft. He contends it is in the fighter pilot's nature to adapt to a changing environment; the essential nature of combat and, therefore, the requirements demanded of the fighter pilot, have not changed significantly over time. Cope challenged researchers to help fighter pilots move successfully into the next millennium by refining selection and training techniques.

5.2 Selection Process Overview

Although United States Air Force (USAF) undergraduate pilot training changed relatively little between 1962 and 1992, training will change dramatically over the next 10 years: Specialized undergraduate pilot training has been implemented and modern avionics suites have been introduced. In their paper "Advances in USAF Pilot Selection," Weeks, Zelenski, and Carretta questioned whether current pilot selection processes will provide pilot candidates capable of succeeding in the next decade's flying training programs. Analyses of new cockpit systems can reveal the human capabilities required for successful training performance. Advances in the measurement of human abilities will permit the better identification of candidates with the abilities required for successful training in complex modern aircraft. The authors suggested that the use of such candidate ability information by pilot selection boards will result in improved person-job match, higher quality trainees, lower training waste, and ultimately, improved air combat readiness.

5.3 Selection Criteria -- Anthropometric and Female Aircrew

Historically, the USAF has imposed body size restrictions on the pilot population to maximize the effectiveness and affordability of high-performance aircraft cockpits. A more recent trend in the USAF, however, is to reduce the restrictions on body size to allow more women and ethnic minorities in the cockpit. Zehner noted in "Assessment of Anthropometric Accommodation in Aircraft Cockpits and Pilot Body Size Selection Criteria" that if pilot body size selection criteria change to become more inclusive, then aircraft cockpit design specifications must also change. Design changes will be necessary to incorporate the following aspects of accommodation: Overhead clearance, operational leg clearance, control stick/wheel operational clearance, ejection clearance, rudder pedal operation, visual field, and hand reach to controls. Analysis of anthropometric data will not only enable engineers to determine the absolute body size limits which define who can or cannot fly a particular aircraft safely, but will also provide cockpit design input for future weapon systems.

In "Characteristics of Female and Male USAF Pilots: Selection and Training Implications," King and McGlohn discussed the complexity of determining psychological fitness to fly. This is particularly difficult to accomplish for women because most data collected has been from male aviators, and female pilot candidates are not a representative sample of the general population--suggesting a certain amount of self-selection. King and McGlohn found that there were no differences in intellectual skills between male and female pilots; however, data suggested greater female extraversion, agreeableness, and conscientiousness. Because women are now allowed to engage in aerial combat in the USAF, training needs may arise surrounding the issue of men and women fighting and enduring captivity together. As USAF female pilots--specifically fighter pilots--increase in number, there will be more data and insight to share with other air forces.

5.4 Current Selection Standards and Future Developments

According to Adams-Roy, in "The Canadian Automated Pilot Selection System (CAPSS): Validation and Cross Validation Results," CAPSS measures pilot candidates' psychomotor coordination, learning rate, multi-task integration, and performance under overload. In five simulator sessions, candidates learn and are computer-graded on everything from straight and level flight to landings. Data summaries include candidates' variability, smoothness, and response time. Predictive and cross-validation studies demonstrated that while CAPSS (which will be operational in 1997) is not a perfect predictor of completion of flying training ($\underline{r}$ = .32), it outperforms the current system. Utility analyses indicated the cost of development and implementation will be recouped in three years.

In "Analysis of Psychomotor Performance of Fighter Pilots During Flight," Solcova, Sykora, Dvorak, and Gadourek documented their interdisciplinary bio-psycho-social attempt to evaluate pilot performance during flight. Instructors rated psychomotor performance while an apparatus took measurements of +Gz and heart rate. As expected, experienced pilots (i.e., those with more than 2200 hours) had significantly better in-flight psychomotor performance than their less seasoned cohorts. Higher performance correlated positively with circulatory adaptation to hypergravity. Individual differences in aerobatic maneuver technique, mood states pre and post-flight, and fusion threshold differences were insignificant. There is an experimental and operational need to develop alternatives to subjective flying performance ratings; this research highlighted the potential for more objective evaluation. While results are promising, the small sample size reported (n = 18) requires readers to treat the study as extremely preliminary.

Bailey and Woodhead identified problems with experimental and operational practices in aircrew selection. Their paper, "Current Status and Future Developments of RAF Aircrew Selection," suggested ways to increase selection measure validity. The RAF uses a Pilot Aptitude score that appears to be the psychological equivalent of the USAF's Pilot Composite score. Validity studies indicated that the RAF battery is a good predictor of early flying training success; however, the results of these studies may be incomplete or misleading due to problems with the criterion. Most often, the global, dichotomous "pass/fail" variable is the criterion of choice for pilot training validity studies. Although this criterion has some advantages, the authors suggested that criterion data should be on a continuous scale to provide more useful information. The authors also supported the use of a domain centered approach validation model.

The Royal Netherlands Navy is concerned that pilot candidates with previous flying experience are failing at a rate near 50 percent. Van den Pol and van der Veen performed an *ad hoc* study to investigate the cause of the high attrition. Unfortunately, they only had 14 subjects with varying flight experience; they noted that candidates

who passed training had performed better on pursuit-rotor and time-sharing tests. To make sense of the failures during intermediate and advanced phases of training, the authors postulated the following about civilian versus military training: Civilian flying involves less stress, most tasks can be completed sequentially rather than having to be performed concurrently, instructors are happy to be paid for students requiring remedial sorties, and low airspeed equates to relatively low workload. Other individual differences such as motivation were discussed but not studied with respect to passing/failing pilot training.

In his paper, "Selection of Future Fighter Pilots," Welsch probed a relatively new concept in German Air Force fighter pilot selection: The measurement of a candidate's natural, unprotected, relaxed G-tolerance. Welsch tracked G-tolerance of pilot candidates who later became student pilots; candidates who were "less qualified" with respect to G-tolerance were also "less qualified" student pilots. While standard medical, physical, and psychological examinations are integral parts of the selection process, the passive G-tolerance test may be an additional item to select especially qualified young candidates for operating fighter aircraft in high-G environments. Screening-in those candidates with above average cardiovascular reflexes against acceleration forces may optimize selection of the future fighter pilot generation.

Spiller listed the ingredients comprising the ideal fighter pilot in "Flying Training - Past Achievements and Future Challenges." Those ingredients include being physically fit, coordinated, intelligent, situationally aware, bold (yet cautious when appropriate), and an inspirational leader. Spiller described the anomalies who became war aces, clearly implying the difficulty in predicting operational success. He also reported current recruiting challenges, effects of down-sizing, and training issues. Spiller has obviously gained insight from years of experience in the service; the researcher's task is to translate that experience into practical suggestions for overcoming today's selection challenges.

5.5 Advances in Selection Techniques

Lenler-Eriksen used data from the USAF Armstrong Laboratory to complete his study reported in "Anaerobic Capacity and Height: Relationship to Simulated Air Combat Maneuver (SACM)-Duration." The effectiveness of a pilot's anti-G straining maneuver is influenced by many factors including anaerobic capacity, straining technique, and motivation. All other things being equal, the pilot with good GDT (i.e., anaerobic capacity corrected for height) can endure time in the SACM environment longer than one with poor GDT. Lenler-Eriksen proposed that testing G-duration tolerance in a centrifuge is an inexpensive and simple way to obtain an estimate of a pilot's physical ability to endure sustained G-forces. Further work in the area--including replications with a larger subject pool and analysis of cost-benefit tradeoffs--are necessary to evaluate the wide-scale implementation of this type of selection screening.

USAF pilot training candidates take a battery of psychological tests measuring intelligence and cognitive abilities. In "The USAF's Enhanced Flight Screening Program: Psychological Assessment of Undergraduate Pilot Training Candidates," Callister and Reztlaff compared candidates' test results with those of commercial pilots. While pilots in general tend to be of above-average intelligence, there were differences between pilot candidate and commercial pilot norms for the CogScreen-AE (a cognitive abilities test). Commercial pilots were better at arithmetic problems and focused cognitive tasks while pilot candidates were better at numeric working memory and dual/divided tasks. While this data collection effort does not provide particularly new information regarding pilot candidate abilities or selection techniques, it does provide improved normative data for untested pilots; thus, it may facilitate longitudinal selection, training, and assignment research.

In "Simulator Based Test Systems as a Measure to Improve the Prognostic Value of Aircrew Selection," Gress and Willkomm described the FPS 80: A simulator-based test system used by the German Air Force as a "hands on test" to estimate a student pilot's ability to perform in later flight training. Students fly four simulator sorties during which they are computer-scored on individual maneuvers and overall performance. High FPS 80 scores correlated well with high flight screening performance--academic ($\underline{r}$ = .38) and flying ($\underline{r}$ = .44). In pilot selection, the predictive strength of the FPS 80 was greater than that of classical psychological tests. The authors stressed that the main advantage of the simulator based psychological test system is the opportunity to view a candidate's response to a complex situation which previously could only be observed in an aircraft (i.e., the simulator provides ease of data collection, lower cost, and increased standardization benefits).

Patterson, Schofield, Howe, and Bonney reported in "Cognitive and Personality Findings Among Special Duty Aviators" that USAF Special Operations Command uses specialized methods including psychological testing in its aircrew selection process. The researchers compared applicants to baseline unit members. They found applicants were superior in cognitive scores, agreeableness, and conscientiousness. Cognitive scores, however, while important to psychologists' ratings, were not especially important to final board decisions. Overall, the psychologist ratings did not differ significantly from the board decisions.

5.6 Training Process Overview

Carroll and Andrews, in "R&D Advances in USAF Pilot Training," summarized the long-term aircrew training research program of the USAF. The focus of this research program is to insure that combat air forces can train as they intend to fight. Specifically, Carroll and Andrews outlined a three-component program of behavioral research, distributed mission training research, and night-vision device training research. Examples of behavioral research included developing training guidelines for the effective use of multiship simulation training. Carroll and Andrews pointed out that merely using the same training techniques in the simulator that an instructor uses in the aircraft is inefficient and may not be very effective; they provided suggestions for change. In the area of distributed mission training research, the authors outlined existing programs designed to drive down the cost and increase the fidelity of networked simulators. Their research program in night-vision device training is designed to produce a cost-effective, comprehensive ground-based training system in the use of those devices.

5.7 Crew Resource Management, Design Issues and Training Analysis Techniques

Hormann described the Facts, Options, Risks & Benefits, Decision, Execution, Check (FOR-DEC) model in "Training of Aircrew Decision Making." Each letter comprising the FOR-DEC acronym represents one of the six different stages in an "ideal" decision-making process.

Hormann explained how the model is integrated into crew resource management (CRM) training units. Feedback from seminar participants indicated high relevance of course content and emphasized the need for authentic scenarios.

'Understanding the Requirement: A Review of Common Problems in Training, Selection and Design" by Cook and Ward provided a comprehensive look at the problems in selecting and training pilots. The authors suggested that these problems can be attributed to a relatively poor understanding of pilot tasks. Non-pilots have a hard time imagining exactly what it is a pilot does, and pilots often have trouble recalling their specific behaviors and thoughts in flight--especially as experience enables their activities to become more automatic. Cook and Ward thoroughly reviewed related literature and provided suggestions for expanding knowledge of pilots' tasks across a range of combined tasks at various critical mission points. This increased knowledge should help researchers identify the key qualities of good pilots and develop more appropriate selection and training methods.

In 'Results from an Aircrew Performance-Based Approach for Determining Intervals for Aerospace Physiology Refresher Training," Bennett and Teachout described recent research designed to determine key aspects of Aerospace Physiology training. Specifically, results included a combination of survey data, archival data, and tests of knowledge retention. Results have been used to redefine refresher training content and validate the USAF's current refresher training concept. Bennett also discussed using archival mishap data to validate aircrew ratings of the likelihood and consequences of impaired performance.

5.8 Physiological Training

Before beginning pilot training, German Air Force pilot candidates received training in the centrifuge. According to Welsch in "Training of Future Fighter Pilots," this exposure to anti-G straining maneuvers and breathing techniques was very effective. The training increased the candidates' awareness of the effects of the high-G environment and their own maximum G-tolerance, which may help them avoid negative experiences of G-LOC during pilot training. Welsch also postulated that students gained self-confidence through the experience, which may enhance their performance in pilot training and be an effective contribution to flying safety.

In "Aviation Physiology Training in the 21st Century," Glass and Wilkinson reviewed several nations' aeromedical training programs to learn what training is taking place (i.e., what type and how often) and what changes have occurred over time. In many cases, there was little to no empirical evidence supporting the training. For example, in a Canadian aeromedical incident review, it was impossible to determine what effect recurrent personal hypoxia experiences in an altitude chamber had on the aircrew's ability to recognize hypoxia symptoms in flight and react appropriately. In an era of down-sizing, such training may be cut dramatically if there is no supporting justification for continuing the training. Data will certainly lead to better-informed decisions. The authors suggested that measurement tools need to be developed to assess the appropriateness of these training programs and their impact on flight safety. They also suggested methods for standardizing aeromedical training internationally.

Because spatial disorientation (SD) is a major factor in class "A" mishaps, Holoviak, Yauch, Previc, and Ercoline proposed that there is a need to expose pilots to the effects of SD (e.g., visual and vestibular illusions) in a realistic training environment to improve their situational awareness and flying safety. The authors noted that the goal of the USAF Advanced Spatial Disorientation Demonstrator (ASDD) is to provide that highly realistic, ground-based SD training to pilots. Feedback from pilots indicated that the scenarios are realistic, and the ASDD provided exposure to a broad range of SD phenomena that would otherwise take years for a seasoned pilot to experience. The authors proposed that early exposure to realistic SD training will lead to earlier SD recognition and the development of coping strategies crucial to a pilot's flying safety.

5.9 Facility Advances

Many people believe that motion-based training is an effective way to teach complex, psychomotor flying and survival skills to aircrew in an economical and safe manner. In 'Review of Motion Based Physiological Training Devices," Mitchell and Leland described the capabilities, applications, and operating/maintenance costs of a variety of aircrew training devices such as those designed for water survival and ejection seat training. Such motion based devices, according to the authors, are maximally effective only when they have low acquisition and operating costs, multiple task training capability, flexibility of use, and high fidelity; they must also be interactive. Mitchell and Leland maintained that future development of motion-based training devices for physiological training should be a cooperative effort among customers, users, research centers, and industry. This cooperation should insure constant quality improvement and lowered training costs.

The German Air Force acquired the Flight Orientation Trainer (FOT) to provide advanced training to aircrews against the dangers of spatial disorientation (SD). Lichtschlager, Scherb, Heinz, and Pongratz, in 'The Flight Orientation Trainer as a Dual Purpose Device: Training Versus Aeromedical Research" described a troop trial in which 22 pilots participated. The results of the troop trial indicated that some of the illusions produced were extremely realistic, but the value of other illusions was hindered by insufficient performance of the visual display system. Some pilots experienced severe airsickness during their FOT flights. Pilots agreed that the FOT would be appropriate for exposing novice student pilots to SD scenarios. Such FOT trials enable researchers to determine which improvements are necessary for making the FOT a more viable research and training tool for a wider variety of pilots.

5.10 Posters Display

Bahbouh explained that dynamic sociometry and sociomapping are research procedures used to analyze interactions between social elements, depicting the social system's inner-structure and the dynamics of its evolution. Kazda and Tomecek used dynamic sociometry techniques to analyze the quality of communication flow, mutual relations structure, critical relations and configurations within Air Force work teams (a project that is still underway). A sociomap presents information in similar fashion to a synoptic map used in meteorology. The sociomap, though, captures strong and weak communication areas, reflects tension build-up, and can predict future conflicts. The authors proposed that this is a useful feedback device for organizations of any size.

Grygoryan and Kochetenko supported the use of computer informational technology (CIT) to avoid problems in aerospace medicine research protocols arising from human tolerance limitations (e.g., dynamic accelerations in the

centrifuge). If mathematical models are created to describe the main human hemodynamic processes during centrifuge trials, the models can be translated into CIT. CIT then allows the researcher to substitute parts of expensive and dangerous trials with computer simulation. These computer simulations may provide researchers with new possibilities for study, economizing research, and minimizing risk to human subjects. The authors believe that CIT will have wide applications in aerospace physiology and medicine.

Palermos, et al. measured subjects' blood muscle enzymes and cardiac rate (i.e., indices of muscular and cardiovascular strain) during an evaluation of the standardized and applied pilot cadet military endurance training of the Hellenic Air Force. There were remarkable changes in serum muscle enzymes between the early days of the cadets' military endurance training and after one month of adaptation. The pre- and post-physical overtraining cardiac episodes were not clinically significant, but their effect on pilot flight ability is currently under study. Based on their observations, Palermos, et al. recommend a stronger endurance training program and increased carbohydrate intake to improve pilot cadet fitness. Results from such studies may be used to improve pilot training and fitness programs.

Researchers Leimann-Patt, Bonanatta, Santarelli, and Romero have seen many pilots eliminated for "sick arteries," but they noted that in most cases, such medical conditions did not necessarily correlate with unsafe flying *per se*. Believing unsafe flying starts "one foot higher," Leimann-Patt, et al. tried to detect student pilots with high propensity for unsafe flying by categorizing them on the basis of their performance on a test measuring psychomotor skills, divided attention, rapidity and accuracy to learn unusual controlled hand movements, and operational criterion in high stressed context. Instructor pilot ratings were used in the validation process. On the basis of their results, the researchers advocated the administration of computerized psycho-neurological tests to fill the gap between the hard and "fuzzy" disciplines.

6. CONCLUSIONS

In an era of increased operations tempo, decreased force size, and decreased budgets, aviators must interact with weapons systems more efficiently than ever before. This Symposium on selection and training advances is extremely relevant in meeting that challenge. The high technical quality of the presentations, coupled with the very wide scope of selection and training issues addressed, allows participants to benefit from the work already accomplished by others.

Because there are many who wish to fly, while flying training remains a very expensive proposition, air forces have implemented selection systems to predict which candidates will be successful aviators. In addition, the demands placed upon fighter pilots are different than those placed upon multiengine transport or tanker pilots; therefore, air forces must determine not only which candidates will be successful in initial training but also which weapons systems those candidates should fly.

Individual nations have attacked these selection problems in different ways. While virtually all air forces use some type of medical examination and cognitive ability measurement (either tests designed for the specific purpose of aviator selection or more general abilities measures), some air forces have implemented screening systems using personality or psychomotor measurement, flight simulators, and measurement of *g*-tolerance or susceptibility to spatial disorientation. While medical examinations and psychological testing can be implemented relatively easily in a decentralized assessment process, screening systems involving centrifuges, simulators, spatial disorientation devices, or other equipment may be cost-effective only for air forces that conduct screening at a centralized location. Individual nations must clearly make their own cost-benefit calculations; however, the presentations in this Symposium provide researchers with many initial hypotheses as well as estimates of potential utility of alternatives in a selection system.

Once a candidate has been selected as a potential aviator, he or she must be trained. Because of the high cost of operating modern military aircraft, air forces are searching for lower cost training techniques and devices that have been routinely available in the past. Lower cost training that results in an inferior aviator, however, is clearly a false economy. As with aviator selection, presentations in this Symposium provide many hypotheses for training techniques and devices that promise not only lower costs but also increased effectiveness.

This Symposium brought together experts from a variety of disciplines who address selection and training issues with a variety of approaches. The broad scope of the program--and the "division" between selection and training--may give the appearance of a less than coherent theme for the Symposium. On the contrary, the varying disciplines and approaches define the Symposium's strength: Issues of selection and training are inseparable. Better selection systems can result in training systems that can be better targeted, resulting in increased efficiency; at the same time, robust training systems can compensate for less than ideal selection systems.

Similarly, selection decisions based on medical, physiological, cognitive, psychomotor, and personality factors clearly interact and must be heeded/analyzed simultaneously. Researchers working in each of these areas must consider the work that is being done in other areas to define the entire selection system. The training system is equally complex; researchers concerned with more global training issues (e.g., combat simulation training) need to be aware of advances being made at the more focused levels (e.g., spatial disorientation awareness training). Researchers looking for better training delivery techniques need to know what advances are being made by researchers looking at methods of task analysis or determining training requirements.

7. RECOMMENDATIONS

There have been significant advances in selection and training in aviation that are described in these proceedings. There are more advances to be made.

First, as many presenters pointed out, every selection and training issue raised in this Symposium would benefit from better criterion measures. It is clearly important for a selection system to be able to separate those who will "pass" from those who will "fail" in initial training. Today, however, that is not enough. Selection systems must also be able to discriminate among those who "pass" to identify those who will be successful in combat. Thus, defining what it means to be "successful in combat" is critical; even more challenging--because opportunities for demonstrating success in combat are limited--is the problem of developing valid surrogate measures for combat success that can be routinely collected in a peacetime, training environment.

Second, training researchers need to move away from being "technology advocates" toward being "technology evaluators." Too often, the measures being used in training R&D consist entirely of internal evaluations of the training by participants in that training (e.g., "pilots liked it" or "pilots believe this system will help reduce accidents," etc.) This observation is not new; review articles in the professional literature routinely point out this problem with training R&D. Training itself is a very expensive proposition; often, inserting new technology into the training system increases initial costs substantially. Without hard evaluation data--the kind of data that can document training time savings or (much more difficult, but also much more useful) document improved combat performance, users will continue to resist changing the training system. The training R&D community must give substantial thought to developing and collecting this type of data, and to designing scientifically supportable evaluations, before blindly purchasing, developing, or demonstrating new technologies.

This Symposium highlighted the excellent ongoing work being done by many nations in designing, developing, and demonstrating selection and training systems. The challenge now--for both the selection and training communities--is to develop the research designs and the appropriate measures to document the operational, practical utility of these systems.

RESEARCH ACTIVITIES OF THE EXPERT LABORATORY IAFAD INTRODUCTORY PRESENTATION

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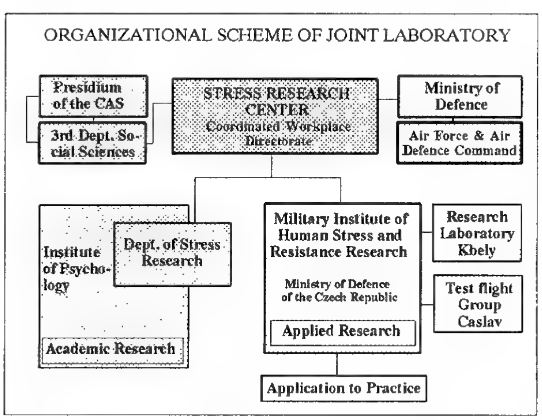
SUMMARY

The Expert laboratory of IAFAD is presented as a new type of workplace in the history of the Czech Air Force. It was founded as part of the Czechoslovak Academy of Sciences fifteen years ago. The aim of the research was the same as it is today, namely to search for ways of mitigating the influence of stress on individuals and human groups in a critical situation. The scientific approach is interdisciplinary, and is called *BIOPSYS*. This term represents the combination of biological, psychological and social disciplines. The fields of research were concentrated into the program *resistance* divided up into the main themes *adaptation* and *aversion*. The numerous problems of characterized by the terms *load, stress, resistance, performance, failure* and the term *adaptation* as a key for setting these systems in motion were resolved at the level of basic research then at the level of applied research. The various results of this research have been successfully used in the everyday running of the Czech Air Force.

1. INTRODUCTION

The institution which is presented in this paper now operates under the name of the Expert Laboratory of the Inspector of Air Force and Air Defence of the Czech Army, previously the Institute of Stress and Resistance Research of the Ministry of Defence.

This was preceded by a specialized institution, founded in May 1981, within the structure of the Czechoslovak Academy of Sciences, initially as the Stress Research Laboratory, which cooperated later very closely with the Air Force as the Center for Stress and Human Resistance Research.

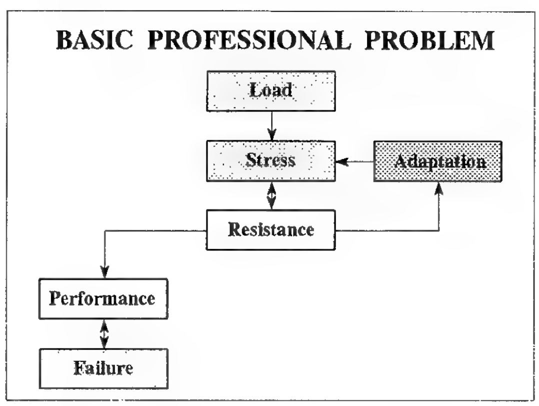


At that time, the Centre consisted of two parts: the Department of Stress Research of the Institute of Psychology of the Academy of Sciences, and the Military Institute of Human Stress and Resistance Research of the Ministry of Defence. The academic part was aimed at basic research work, the military one at putting the results of the basic research into practice. This is why it also had a test pilot squadron at one of Czech Army airfields aimed at human factors analysis. The laboratory has cooperated with many academic institutions in our country and abroad. For example, it has participated in the INTERCOSMOS Programme since 1983 and in the European Space Agency since 1993.

Moreover there has been established a new institution, Danwell Inc. It is a private commerce and research organization, that is oriented towards research and its practical applications in cooperation with Expert laboratory and other partners in the East and West, mainly in the field of space biology, psychology and sociology.

2. RESEARCH TOPICS

The main problems that are now being investigated in both institutions are represented by the keywords *load, stress, resistance to stress, performance, failure, adaptation*. The central theme of the Laboratories is the resistance of individuals and small groups to stress. The basic approach is interdisciplinary, viewed from social, psychological and biomedical perspectives. The main aim of the research is to search for the link between psychosocial events, personality traits and psychophysiological responses. The activities of the Laboratories are also focused on the search for interactions which mitigate the negative effects of stress on individuals and on their health, for example on social relations in a social complex.



The program is based on a methodological interdisciplinary approach, called *BIOPSYS*. This name expresses the cooperation of three scientific disciplines - biology, psychology and sociology. On this basis, the

Paper presented at the AMP Symposium on "Selection and Training Advances in Aviation", held in Prague, Czech Republic, in May 1996, and published in CP-588.

laboratory's specialists concentrate on the analysis of the real picture of our Army and of its needs at present. They have made many recommendations for the actual and strategic transformation of our Army, especially concerning problems of aviation, such as noise problems from air traffic, the psychological load of pilots at a time of reorganization of our airfield network, and problems of air safety.

3. RESULTS PRESENTED

The research program can be summarized under the heading of the *resistance* of individuals and groups to stress. Two leading projects are: project *AVERSION [1, 2,3,5,6,9,11,13,16,17, 18]* and project *ADAPTATION [4, 7, 8, 10,12,14,15]*.

3.1. What do we understand by the project *AVERSION*? It has the following aims:

1) to answer the question as to what are the mechanisms giving rise to social aversion toward particular social groups and that on the part of this group (for instance élitist self-preservation, etc.) as well as on the part of its social environs (such as insufficient information, and insufficient financial contribution to the region),

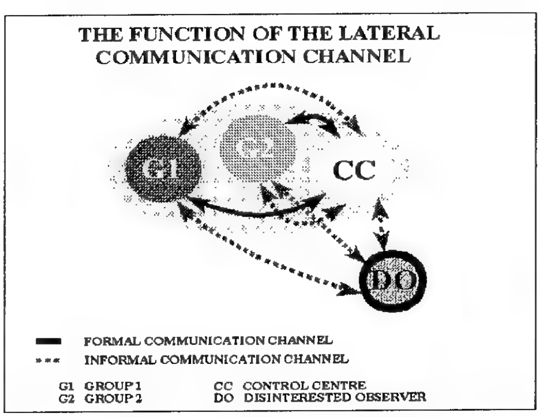
2) to search for methods having

a) a buffering effect - diminishing the impact of a negative social attitude towards certain professional groups (accusations of ecological damage, etc.),

b) a preventive, mitigating effect - preventing the rise of averse behaviour and/or "pacifying" this behaviour.

3.1.1. In this area we participated in the international program of space research conducted by the European Space Agency. The main aim of this research programme was the analysis of human behaviour during simulated long duration space missions.

3.1.2. As another example of *AVERSION PROGRAM* the theory of a secondary, *LATERAL COMMUNICATION CHANNEL [13,16,17]* was formulated. This theory describes the importance of using an informal communication link between two or more groups, especially in the case of aversion between them. This mechanism can help to eliminate internal tensions in groups which operate in dangerous (risk) situations, such as space flight. Results were also used with success in the mitigation of brief disorders in military units. They were also used in solving the problem of negative attitudes of populations in the vicinity of military airfields.



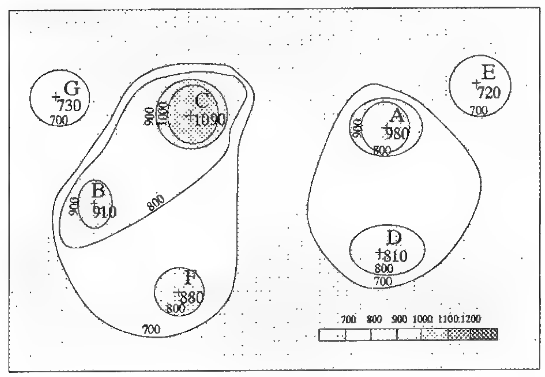
THE FUNCTION OF THE LATERAL COMMUNICATION CHANNEL

3.1.3. In the framework of the program Aversion, a new method of *DYNAMIC SOCIOMETRY [19]* was developed and proved in practice at our laboratory. This consists of the expression of parameters of social, psychological and physiological reactions at different levels of characteristics of individuals as members of a group. Using the fuzzy set theory, the parameters are integrated and co-ordinated into a graphic representation in the form of what we call a social map.

It could be shown that this enables not only objective expression of social interactions within a group, but also consideration of its homogeneity, possible interventions which should be undertaken by its leader and also prognostics of its future social evolution.

The usefulness of this method for air forces practice in the selection of air crews, staffs of units, the personnel for air traffic control, for special air combat task units has been proved in practice.

DYNAMIC SOCIOMETRY



3.2. The aims of the project *ADAPTATION* are:

1) to define factors influencing the work performances of pilots and crews (personality traits, level of abilities and experience),

2) to define stressors related to the work performances of pilots and crews,

3) to assess criteria of selection for highly demanding activities, to develop new methodologies of training and control of the actual level of work performance.

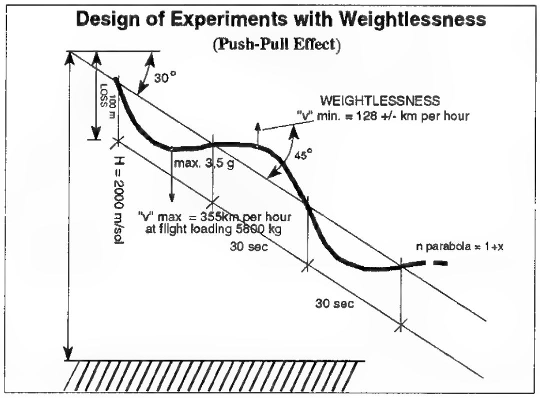
The following are several examples of the activities of the Laboratory:

3.2.1. It participated in an experiment with microgravitational effect on pilot performance, using simulated weightlessness during airplane Keplerian trajectory flight.

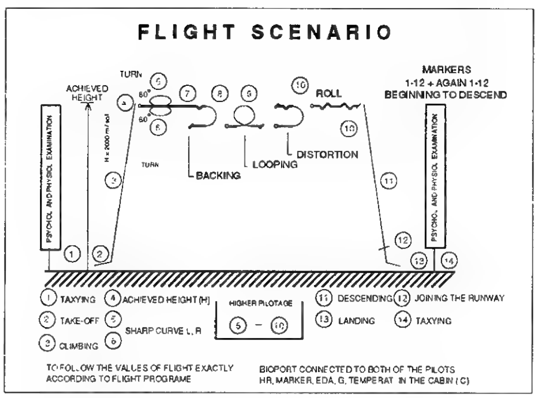
In relation to the new problem with "the push - pull" reactions, several experiments in alternating hyper and zero gravity were performed leading to minimal disturbance of the state of the pilot. The data are still under evaluation.

3.2.2. In the area of the methods of pilot selection, aimed at *OBJECTIVE ASSESSMENT OF PILOTS IN-FLIGHT PERFORMANCE [7, 8,10,12]* This method is based on continuous monitoring of pilots´ functions during a standardized aerobatic flight. Pilots activities represent a model of any stressful situation, whether in army or civilian life. We do not consider the best

approach to be the evaluation of pilots' in-flight performance under laboratory conditions. We therefore realized several sets of flight experiments.



3.2.3. Apart from the described areas of our working problems, the laboratories concentrate on specific



questions, which have a more physiological basis. That is for example the problem of cardiovascular method for the prediction of late consequences of early causes of diseases, which can be the cause of the premature end of active flight service. *[20]* This is the work of Dr.Drska, which could be summarized under the title of "Single Beat Late Potentials and the Risk of Human Factor Failing Due to Sudden Cardiac Death". Taking the results of our French colleagues of echocardiography showing right heart hypertrophy in fighter pilots into account, the new method of evaluation of the state of heart muscle presented by Dr.Drska could perhaps be used for this purpose.

4. CONCLUSIONS

Concluding, the laboratories are able to use a part of their capacity to help solve several problems presented by AGARD. We are of the opinion that in the field of problems of technical development, human factors might be decisive, such as those related to the possibilities of the increase of hypergravity tolerance, mitigation of fatigue related to long lasting flights, problems of disorientation during low level flights under adverse weather conditions, team or group stability and performance prognostics et sim.

Their research topics are:

1) Stress mitigation under conditions of chronic stress.
2) The relation of stress to professional working performance. It seems that performance remains uninfluenced by stress if it is of the eu-stress character. This should be studied in experiments with hypergravity during standardized aerobatic flight.
3) Profound analysis of the psychomotor performance by analysis of real flight curves during aerobatic manoeuvres, taken as a form of pursuit of some ideal flight curve.
4) Prognostics of group performance under stress based on dynamic sociometry and social mapping analysis.
5) The performance of women under stress as well as their style of coping, are to be studied in more detail.
6) The problem of limited space and decreased motor activity during social deprivation and confinement during long space missions as a negative, stress inducting and/or enhancing factor.

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Fighter Pilot - A Moving Constant

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Summary

This presentation forms the keynote address to the AGARD symposium held in Prague over 27-30 May 1996. The presentation aims to show that the requirements, capacities and essential characteristics of the fighter pilot, and his/her role, have not altered materially over the years. Whilst the procedures, tactics and weapons employed in aerial combat have changed considerably with developments in technology the primary task of the fighter pilot remains that of gaining, retaining and exploiting air superiority. Throughout the relatively short history of airborne warfare the fighter pilot has always sought to achieve an optimum combination of knowledge, technique and technology. The presentation seeks to show that, despite technological advance, the evolution of aerial combat requires the fighter pilot to constantly function at his/her maximum capacity to optimise the combination of weapon system and operator, and that the characteristics of awareness, mental capacity, application, determination and enthusiasm had equal validity to the pilots of World War One as to those of today. The spiralling costs of modern military flying training result in relentless pressure on today's training budgets and intensify a need for ever-more-reliable and accurate methods of identifying the right characteristics in candidates for training. Nevertheless the basic raw material of the fighter-pilot remains largely unaltered. The solutions to the current aircrew physiological and psychological problems facing designers of future fighters will not be found in seeking a radically different type of individual to fly them.

Fighter Pilot - A Moving Constant

Ladies and gentlemen, good morning. One of the things I hope to discover whilst in Prague is why all of the twenty-five people that Doctor Macmillan approached before me, to give this address, could not be here today.

As you know our symposium starts with a theme to the effect that the increasing complexity of modern air operations has lead to increased demands on the future fighter pilot in both physiological and psychological terms.

The theme goes on to suggest that :

The next generation of highly agile aircraft, capable of very high rates of manoeuvre and very high g-forces and of operating at very high altitude, will produce conflicting sensory inputs. These will be exacerbated by head-mounted displays and may result in an increased risk of spatial disorientation.

The hypothesis for our symposium is that current selection and training methods are not adequate to enable future pilots to cope with the next generation "fast-jet" environment.

Well, is it true? Are we in danger of exceeding the physical and mental capacities of the fighter pilot as we know him? Are the capabilities that we have traditionally sought to identify in selecting pilots for training no longer valid? It is true that the advent of fly-by-wire control systems have made hand-eye co-ordination and motor skills less important. Should we now be looking for a new kind of animal, a kind of military pin-ball wizard to control the airborne video game? More than one recent article on the subject has suggested that instead of an airborne warrior we now need a "managing director" in the cockpit. Has technology now changed the nature and the environment of air combat out of all recognition?

I suggest not. Necessity is the mother of invention, and in military aviation we are in fact well-used to change, it is the lifeblood of what has been one of the fastest developing technologies in our modern world. Warfare will always be conducted by men, not machines - the machines are only tools. But in the case of the fighter pilot those tools have become incredibly complex and costly devices, and the military pilot has had to adapt to keep pace with their capabilities. I contend that the essential nature of air combat, and therefore the basic requirements of the fighter-pilot, have not changed.

The role of the fighter pilot remains to wage war in the air, to gain and maintain air superiority and then to exploit it. He must adapt to his environment without losing sight of his aims. Perhaps if we wish to see the future we can productively start by reviewing the past. Over the next 25 minutes or so I intend to examine a few snapshots from the history of military aviation to try to see how much, and in what ways, the fighter pilot has changed throughout his/her existence. You will have already detected my first instance of change, albeit a relatively recent one, from my inclusion of the female gender in my last sentence.

I hope you will forgive me if most of my references are to the history of my own air force but time precludes covering everyone and it made research a lot easier.

Throughout my little snapshot tour we will examine the development of;

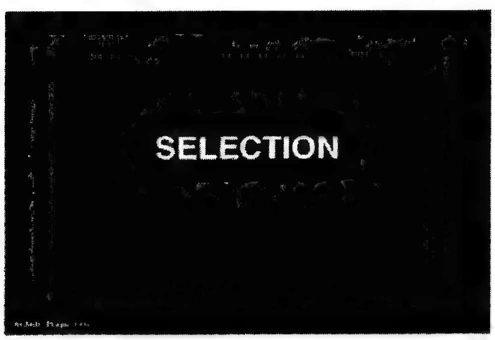
Pilot aptitude testing and selection techniques,

- The physiological criteria and stresses which were Present,
- The nature and complexity of the air warfare environment.
- The training systems which supported operations at the time.

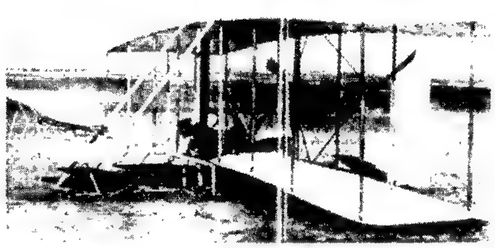
Paper presented at the AMP Symposium on "Selection and Training Advances in Aviation", held in Prague, Czech Republic, in May 1996, and published in CP-588.

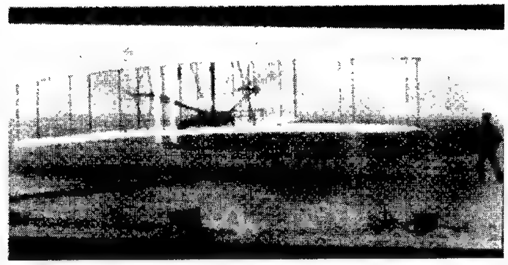
Let us look back at the beginning, and I mean the very beginning, of powered flight, with the Wright Brothers. The selection of the pilot for this historic event appears at first glance to have been made on the basis of chance. It was originally decided on the toss of a coin. But, on closer

examination we see that it was actually far more appropriate than that. Wilbur, who actually won the toss, forfeited his chance of becoming the first true, powered aircraft pilot when he stalled the "flyer attempting to take-off on 12 December 1903. Natural selection on the basis of proven ability therefore came into play; and after 5 days repairing

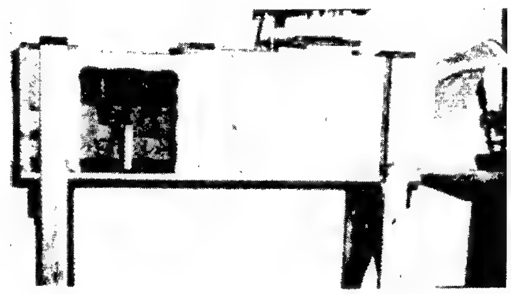


the damage, Orville Wright took his turn and succeeded, making history on 17 December 1903. But both of the Wright brothers met extremely stringent selection criteria, even by modern standards. Few pilots nowadays are called upon to not only design their own aircraft, but also to first invent a





completely new flying control system with which to fly it. Even fewer have to make their own engine! Just as well perhaps or I doubt very much whether I should be allowed to wear a pilot's brevet today.



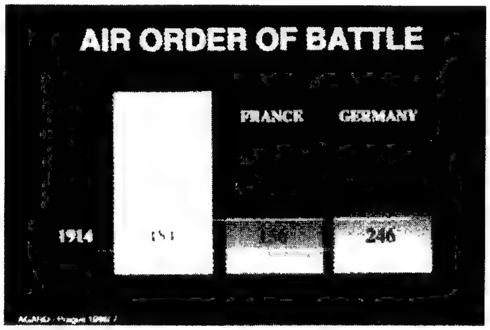
The Wright brothers also built their own wind-tunnel to test their theories. Their training for the flight comprised extensive research into other pioneers' achievements and considerable experience of gliding, during which both the design of the aircraft and its wing-warping control system were thoroughly tested.

The physiological aspects of their flights were less demanding. Maximum speeds were in the order of 40 mph and maximum altitude rarely exceeded the aircraft's wingspan. There was no need for an oxygen system! However, there was great need for the qualities which lead to their success:

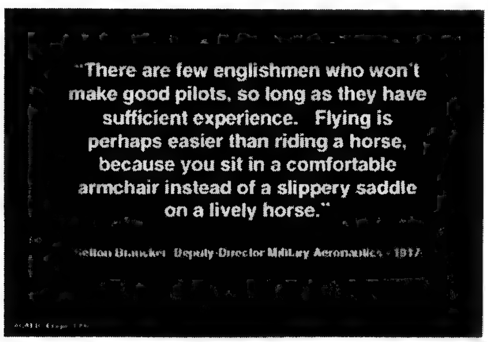
- determination,
- a great willingness to work,
- willingness to learn from others,
- and enormous enthusiasm.

And these remain essential requisites in candidates for pilot training today. But the world at large and military man in particular was slow to grasp the significance of the Wright brothers' achievement. The Wright brothers offered their invention to the US Army for reconnaissance purposes, but it was rejected.

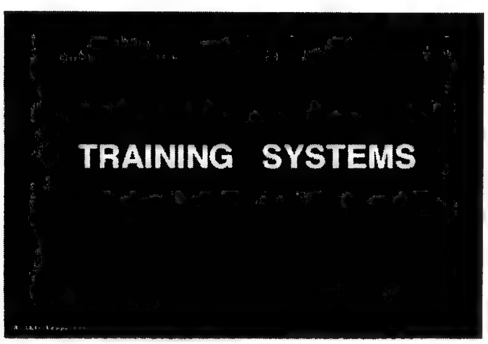
Ten or so years later it was to be a somewhat different story. At the start of the first world war the British and French had 269 aircraft between them, Germany had 246. Their role was to carry observers for artillery spotting - the potential for an entirely different kind of warfare was not immediately realised. Nevertheless the fight was soon ferocious and bloody. During the first years of the air war the life expectancy of a pilot was two months, shorter than that of a soldier in the trenches. Perhaps that was not surprising......



What criteria were used to select the pilots? There were none really, they selected themselves by their enthusiasm and by volunteering. In this respect things were to be slow to change. Given the attitudes at the time this is perhaps hardly



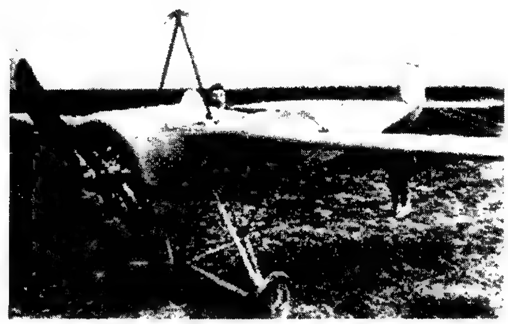
surprising. "Training", if you can call it that, consisted of little more than how to take-off, turn and land. In 1916 British would-be pilots were required to gain their own



Royal Aero Club Aviator's Certificate at a civilian flying club, before applying to the Royal Flying Corps or the Royal Naval Air Service. The published arrangement was that the War Office would reimburse their costs up to £60 if they were successful, and accepted; almost overnight the flying club fees for such training were reduced to an almost universal £60.

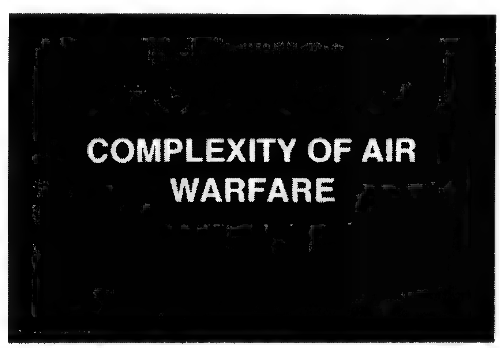
The RFC's Central Flying School taught only meteorology, map-reading and basic mechanics. Flying training was aimed at teaching pilots to drive a reconnaissance platform, be able to land in a field near the army headquarters, taxi up to the appropriate general's tent, salute him smartly and tell him whether the enemies horses were foddered and rested. They were equipped with little more than their initial enthusiasm and the hope that they had the ability (and luck) to survive long enough to learn their new profession as they went along, not many of them did. But things had to change, the "Fokker Scourge" of 1915 saw to that.

By the end of 1915 the British training organisation comprised 18 reserve squadrons, 8 service squadrons and the Central Flying School, all producing pilots in great numbers as cannon fodder to replace the losses. But the great breakthrough in training for the RAF came in 1916 when Major Smith-Barry began training instructors to teach ab



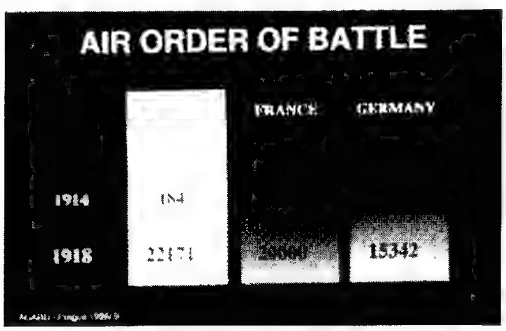
initio military pilots to fly using twin-control aircraft equipped with Gosport tube intercoms. The instructor learnt to teach aerobatics, formation flying, spinning and even how to exploit the torque effect of the radial engine when turning. They began to prepare student pilots for aerial warfare.

The aircrews began by carrying revolvers, rifles and eventually hand-aimed machine-guns, but, when the French pilot Roland Garros bolted metal deflector plates to his aircraft's propeller he invented the first real fighter. This was

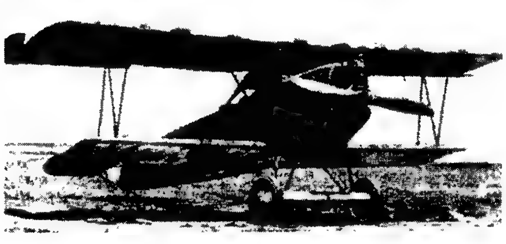


swiftly improved upon by Fokker's invention of the interrupter gear which allowed machine guns to fire through the propeller and the emergence of the aircraft as a weapon of war in its own medium was complete.

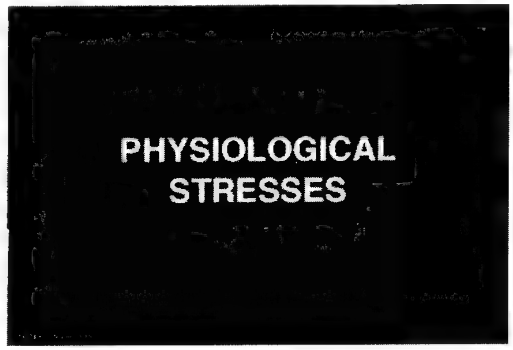
By the end of the war the concept of the warplane and the mystique of the fighter pilot had been well and truly established, with the red baron, Manfred Von Richthofen becoming the top scoring pilot with 80 kills to his credit before he himself was killed. By 1918 the opposing sides' air order of battle had grown 100 times. The opposing sides held inventories totalling over 50,000 aircraft. Military aircraft such as the Fokker D VII were capable of top speeds of 125 mph and altitudes of over 18,000 feet. All without the comforts and physiological assistance of



cockpit heating and oxygen systems. None of the aircraft had any form of G-meter of course, that was a concept of which



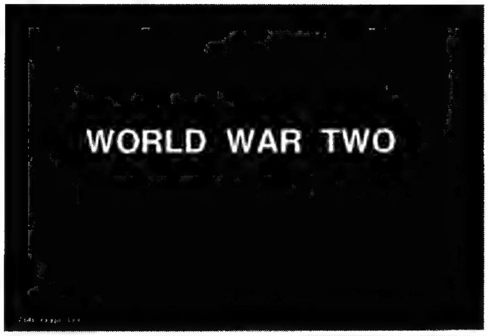
the pilots were largely ignorant. They just pulled until they achieved the positional advantage they desired, they greyed out, or the aircraft structure failed. However, I am advised by the Shuttleworth Collection that accelerations of about 6 G were possible from the most advanced machines; perhaps the cold worked to their advantage in assisting their G-tolerance? At those speeds the rates of turn and pitch must have been impressive. Roll rates were, however, relatively slow. The pilots were not slow to recognise and capitalise on the peculiarities of their machines, and the gyroscopic effects of radial engines were soon allied to flick/incipient spinning manoeuvres to produce arguably comparable, or even higher, turn rates than are prevalent today.



Principles of air combat were evolved that are still valid, and men like McCudden, Boelcke, Rickenbacker, and Foncke became household names. But were they "knights of the air" engaged in chivalrous single combat, as the movies would have us believe? They were not. It was bloody combat where every technological advance was seized upon and exploited to optimum tactical advantage. By the latter stages of the war air battles involved large numbers of opposing aircraft with sometimes forty or more aircraft on each side. Combat took place at remarkably close quarters - in V M Yeates' book, "Winged Victory", the author recounts the harmonisation of the

machine guns on a Sopwith Camel "they obtained a group right in the middle of the sight at slightly less than thirty metres, a trifle longer than the official distance". Forty or fifty aircraft dogfighting in high-G and gyroscopic turns at speeds around one hundred m.p.h. at ranges of a few car lengths, think about it next time you are driving on a freeway or autobahn.

They had no more assistance, in terms of their flying clothing, than a thick sweater and a couple of extra pairs of socks. Yet, in a few short years they had invented most of the enduring disciplines of air warfare and also discovered what was to become an abiding principle - that the combination of technology and pilot capability must be perpetually reviewed and optimised in order to win.

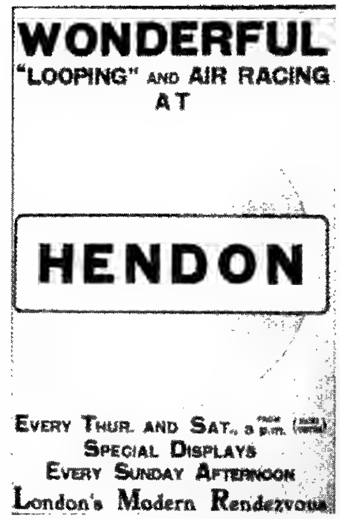


Twenty years on what had changed? What of selection? Wing Commander Pat Hancock OBE DFC, a spitfire and hurricane pilot during the battle of Britain, recalls his

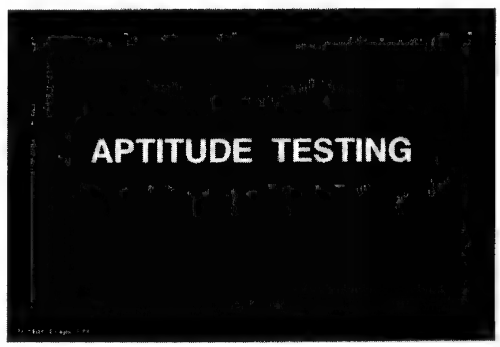
selection process as responding to advertisements placed in the "quality" newspapers and attending for medical examination and interview, so I suppose the answer in this respect is not much.

An interest in sport and a sound education were deemed essential, as was evidence of a real interest in flying. This was customarily demonstrated by the candidate having invested some five shillings in taking a flight with one of the numerous travelling air circuses which offered air experience

sorties at that time. Unfortunately young Mr Hancock had not availed himself of such an opportunity, but was much relieved to find that overseas travel and a detailed knowledge of Montreux, which he shared with the chairman of his interview board, was an acceptable alternative.

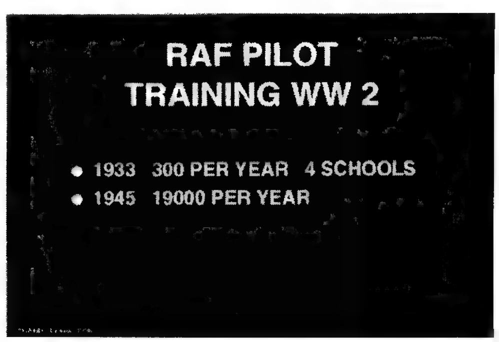


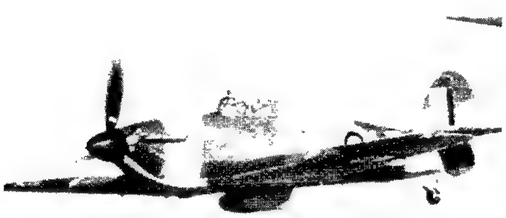
But unlike the outbreak of the first world war, nearly all the training was conducted in the Air Forces, at Service flying schools and the costs of fatal accidents and other failures in training were made obvious. In an attempt to reduce those costs and maximise the output of the training machine to the front-line squadrons, the RAF in 1942 introduced pilot selection by actual flight testing. By 1944 all categories of aircrew were selected by scientific methods of



aptitude testing, for the first time formally recognising the rising spiral of costs which has continued to today, to make today's fighter pilot arguably the most expensive human commodity in the world. But if, in 1938, selection for pilot training remained more of an art than a science, training itself had continued to improve; but it was still far from perfect.

The benefits to ab initio students of formal tuition, by properly qualified and experienced instructors, were

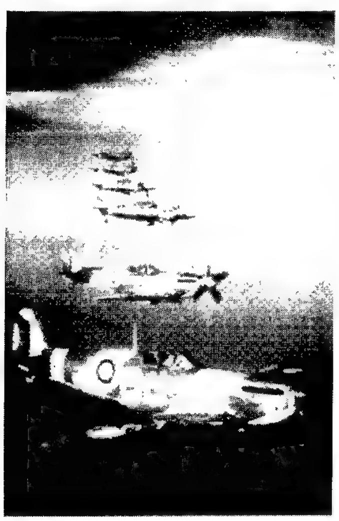




accepted and the student pilot progressed through a sequence of progressively more and more demanding aircraft. He was taught aerobatics, instrument flying, gunnery and bombing techniques. Again, by 1939, of necessity, the training systems had to be expanded enormously to cope with the huge demand for pilots. But training takes time, and much activity had to be exported from the dangerous skies over Britain. Output rose from 300 pilots per year in 1933, to over 19,000 per year by 1945, most being trained in Canada, Australia, and New Zealand.

However there were still aspects which would horrify flying instructors today. Wing Commander Hancock clearly recalls his conversion to the spitfire, which consisted of being given the pilot's manual for the aircraft to study, time to familiarise himself with the cockpit and then taking one out to try it, which he says he accomplished without difficulty!

The aircraft had become faster. Speeds at the time of the battle of Britain were typically in excess of 300 mph and before the end of the war we were to see the advent of jet-, and even rocket-propelled fighters. They were more heavily armed, and longer ranged, both in fuel and gun terms, which meant that engagement distances were measured in hundreds of metres rather than the tens which had characterised the previous conflict, and the air battle ranged over a theatre measured in hundreds of miles. Despite these greater distances the advent of GCI radar meant that hunter nevertheless found hunted. Engagements took place involving entire squadrons and wings of fighters attacking streams of over 100 bombers and escorting fighters, and later in the war the thousand bonber raid was to be invented.

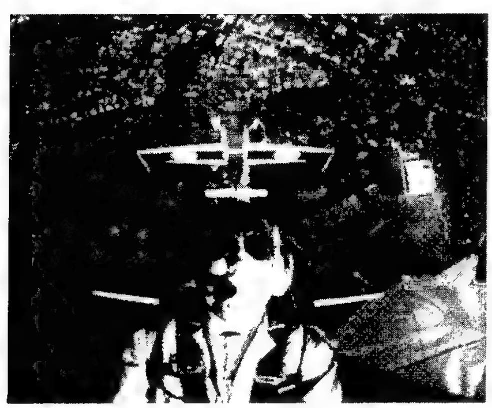


They flew, and fought, higher. For example later marks of spitfire could reach 40,000ft, made possible not only by the aerodynamicist and the supercharger, happily the crews now had the assistance of cockpit heating and oxygen systems. The higher speeds meant stronger airframes. Although no figures for max permissible G were published for spitfires they were built to a structural deformation tolerance of +10G and structural failure at around 14G. Still there were no measures to assist the pilots

in tolerating high g-loadings. Usually the pilot quit before the aeroplane and typical combat manoeuvring seems to have involved loads of up to 6 or even 7 G. Pitch rates are estimated to have been around 15 degrees per second. The spitfire was in particular very sensitive in pitch. G-arising rates could therefore be very high and many aircraft .and pilots were lost, without explanation, far from enemy action.. Perhaps G-loc is not as exclusively modern a phenomenon as we think?

The role of air power and that of the fighter pilot remained the same. Like their world war one predecessors they sought to optimise the combined capability of the man and machine weapon at their disposal.

Well, what of today? Have we gone as far as man can go? Have we really reached, or even begun to exceed, the capacity of the human brain and body to cope with the physical and mental pressures of the air combat environment? Has the nature of air warfare changed to such a degree that today we demand reactions and skills that the pilots of the first and second world wars would not be capable of? I do not believe that. In military aviation we have enjoyed a long-standing love affair with technology and we love declaiming that with each new step in technological progress the world will never be the same again. But are we getting carried away with ourselves, are we starting to believe the hype that the media regularly dresses us in?



Let us briefly look outside the military circle. Mr Brian Lecomber is a one-time winner of the British Freestyle Aerobatics Championship and a practising display pilot. Although he would be the first to admit that the duration of the time he spends at high G levels is much less than that of our fighter pilot the G arising rates necessary for international standard display aerobatics are very high indeed, and unlike air combat rapid changes from high order negative G values to high order positive G regimes are both common and frequent. Brian routinely operates between + 9 and -5G, without the assistance of any anti-G clothing. Lest you imagine that comparisons with our fighter pilot cease there, I assure you that rates of pitch and yaw in a competition sequence compare quite closely with those experienced as maximums during air combat and the requirement for precise orientation following repeated, protracted flick manoeuvring must approximate to the spatial awareness problems that we postulate for the pilots of EF2000, F-22 etc. By the way, Brian is 50 years old!
If, like me, you watched the movie "Top Gun" and laughed at Hollywood's "ridiculous" portrayal of 2 jet fighters, canopy to canopy in a 4G bunt, and laughingly told those

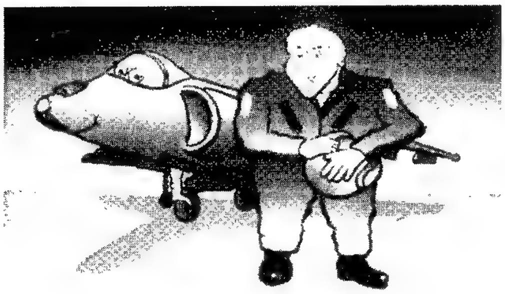
watching with you that it just cannot be done - watch this video clip!

Every now and then a small dose of humility is good for us. I do not underestimate the problems which the next generation of aircraft will bring, I merely try to put them in what I believe is the correct perspective. Techniques of positive pressure breathing under G. Anti-G suits comprising chest-pressure jerkins as well as trousers, and centrifuge training have already been shown to offer the fighter pilot a capability for a sustained 8.3G without the need for any form of straining manoeuvre. We should remember that people like Mr Lecomber have only the straining manoeuvre.

Research into the physiological regimes of air combat has come a long way in a short time. The fighter pilot himself has, over the same time, had to adapt to rapidly changing technology and exploit it, or risk losing the essential battle for air superiority. I suggest that over the 80 or so years of the history of air combat the pressures on, and capabilities of, the human beings we turn into fighter pilots have not altered greatly. Aircraft speeds have increased, but so have engagement distances. The lethality of the modern missile armed fighter is many times greater than its predecessors which will tend to increase the pressure on future pilots, but so is its cost, and therefore the numbers of players in any given fight are now much lower which must, to some degree exercise a balancing influence. Similarly advances in air-to-air missile technology offer extremely agile weapons capable of being launched at 90 degrees off bore-sight, which should reduce the need for tomorrow's fighter pilot to use very high g-levels in turning to get onto his opponent's tail, although it may also increase his need for extreme agility when manoeuvring to avoid his opponent's weapons!

Helmet mounted displays and sights, coupled with voice-activated weapon systems offer much to reduce the workload and increase the lethality of modern fighters. I contend that the pace of events within air combat and the required reaction times have therefore altered little; they remain what, in their quest for superiority, fighter pilots have always made them - the maximum that can be extracted from a human being. Returning to helmet mounted displays - yes, they may offer an edge to tomorrow's pilots, yes we would like them to be so light that they do not critically exacerbate the pilots' neck strain under high G. Nor should they prejudice his or her safety during ejection; but if we cannot have the ideal solution I doubt that many air forces will give away a decisive edge. What is the value of a healthy, unstressed neck on a pilot who has lost a combat and is about to be shot down. If we have to, we will, in future continue to do what fighter pilots have always done - balance advantage against risk; remember Roland Garros and the ricochets involved with his armour plated propeller?

The present anthropomorphic limits which aircraft design places on current RAF aircrew will fit 95% of the population of the UK. This is one of our young Harrier pilots, with carefully posed female admirer. With female Tornado pilots and navigators in the RAF today, we could reverse those roles! Are we really now to seek a different animal for the next generation of fighters? I doubt it. Perhaps future G-stresses will produce requirements for maximum lung capacity, minimum heart to brain distances, shorter limbs to minimise potential for blood pooling and stronger neck



muscles. That might change the requirement to one which only the remaining 5% of the population can satisfy! It may make theoretical combat sense, but you will notice the absence of any admiring young lady, and I assure you it would do nothing for recruiting.!

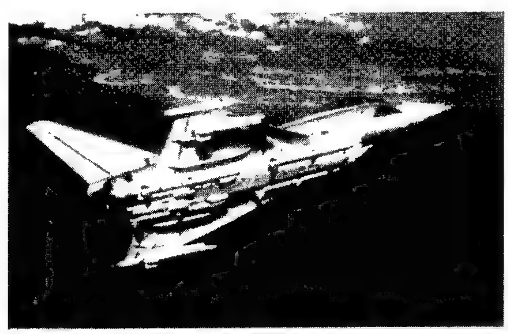
The fighter pilots of world wars one, two and today should have no difficulty recognising themselves in each other. That is hardly surprising since evolution can hardly be expected to have achieved a great deal of change in the human animal in only 80 years! But some things have undoubtedly changed, the cost of military aircraft, the ever increasing pressure on military budgets and the frightening cost of training. A fast-jet pilot has cost the RAF £3 to 3.5M to train by the day he sets foot on his first squadron.
The pressure to pick the "right stuff" first time is enormous

and I know that my own air force is concentrating on improving its ability to accurately identify that ill-defined, but all-important characteristic of "capacity" in its selection process. At present our pilot aptitude selection techniques give only a prediction of success at the basic level of flying training; we are forced to leave it to airborne performance to discriminate between the fast-jet-capable student pilot, and

the somewhat less demanding requirements of multi-engined and rotary-winged flight. We cannot continue to waste the huge sums of money expended on training failures. We will continue to face enormous pressure to repeatedly scrutinise our training systems in order to find economies and I am sure that many delegates to this conference will be familiar with the opposing pressures of economy on the one hand trying to drive training hours away from the squadrons to the cheaper aircraft of the flying training schools and the evolving demands of policing and peace-keeping operations on the other driving a need for new tactics and procedures which can only be developed and practised by the squadrons involved.

I have no answers to these problems. They have been with us some time. No doubt new aircraft will produce different and unusual sensations for our pilots, but pilots will get used to them - they always have, but it would be nice if they could do so without accidents en route. That is a challenge which our future course design teams must face.

Gradually, but inexorably we are improving our performance. Perhaps other speakers will try to forecast how we will select, train and equip tomorrow's fighter pilot for his task; I do not intend to try. But I do know that the basic material we will have to work with will not change. The



price for failing to produce that optimum combination of man and machine is defeat. How many of our army and navy colleagues relish the prospect of combat where their opponent holds air superiority?

The problems are ours, the answers must, in many cases, come from you. How will we take our fighter pilot successfully into the next millennium? But that is what we have come to Prague to discuss. I hope that I have set the stage. I wish you all an enjoyable, stimulating and productive conference. Thank you for listening.

Advances in USAF Pilot Selection

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SUMMARY

Although modern aviation technology provides tremendous advantages, there is concern that complex cockpit systems may introduce psychological problems for aircrew. This concern is particularly relevant for pilot training. Such problems could result in loss of life and increased training costs. For trainer aircraft currently used in United States Air Force (USAF) Undergraduate Pilot Training (UPT), training costs are high. The cost of an eliminee from pilot training can be as much as $350,000 depending on when elimination occurs in the training process. In the past, pilot selection systems have helped identify those individuals most capable of successful performance in UPT. In the future, pilot selection systems can be developed to help minimize any adverse training impacts of modern aviation technology. Analyses of new cockpit systems can reveal the human capabilities required for successful training performance. In addition, advances in the measurement of human abilities allow us to fine tune pilot selection systems to identify candidates having the ability profiles required for training with complex modern aircraft. Use of candidate ability information by pilot selection boards results in improved person-job match, higher quality trainees, lower training wastage and ultimately, improved air combat readiness.

1. INTRODUCTION

In 1962, student pilots may have eagerly anticipated their first flights in the United States Air Force's (USAF) all jet flight training program. Over the next 52 weeks they would learn contact, instrument, and formation flight in the T-37B, USAF's new primary trainer, then sharpen their skills in USAF's advanced trainer, the T-38A.

In 1992, the sons and daughters of those earlier student pilots may have eagerly anticipated their first flights in USAF's flight training program. Over the next 52 weeks they, too, would learn the basics of contact, instrument, and formation flight in the same type of aircraft (possibly the same aircraft) their fathers flew a generation earlier.

USAF Undergraduate Pilot Training (UPT) changed relatively little over the thirty years between 1962 and 1992. Instructional methods were modified as advances in computer technology permitted economical use of flight simulators and computer-aided instruction. Training syllabi were tailored periodically to accommodate shifts in operational emphasis. The basic tasks taught in primary and advanced flight training and the aircraft in which they were taught remained constant. Student success or failure in this long-lived training program has been the criterion against which our current pilot selection methods have evolved.

UPT has changed significantly in the past three years, and will change dramatically over the next ten years. These changes give us cause to question whether the standards and expert judgment applied in current selection processes will provide us with pilot candidates capable of succeeding in the next decade's flying training programs.

2. CHANGES IN UNDERGRADUATE PILOT TRAINING

Age and service life limitations of the T-37 and T-38 fleets have been the catalysts for changes in UPT. The need to train student pilots in skills relevant to the current and future generations of operational aircraft has defined the nature of those changes (8).

The T-37B entered USAF service in 1959. One of this jet's virtues as a primary trainer was simplicity--its systems were no more complex than they needed to be to introduce novice pilots to jet flight. State-of-the-art for 1959, the T-37 is equipped with round dial instrumentation to display flight, orientation, and raw radio navigation information. The instrumentation is minimally integrated, with discrete and poorly arranged gauges presenting separate bits of information.

The T-38A entered USAF service in 1962. This aircraft carries instrumentation characteristic of operational fighter aircraft of its era: round dial flight instruments, an attitude director indicator (ADI) with flight director, and a horizontal situation indicator (HSI). The ADI and HSI provide integrated displays of attitude, position, and navigation information, as well as flight command cues to aid pilots during instrument approaches.

The classic instrumentation in these trainers appears primitive when compared with the cockpits of current and projected operational aircraft. Sophisticated avionics suites incorporating

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integrated multifunction displays and flight management systems have become standard in contemporary aircraft of all roles and missions (e.g., C-17 transport, B-2 bomber, F-22 fighter), and will pervade the existing operational fleet as mature aircraft (KC-135, C-130) are refitted with "glass cockpits."

The disparity in cockpit complexity between trainer and operational aircraft creates an undesirable discontinuity between the skills and knowledge acquired in UPT and the skills and knowledge required to begin mission qualification in operational aircraft. USAF took a major step to correct this deficiency in 1992 with the acquisition of the T-1A, a military version of the Beech 400 business jet. The T-1 sports an impressive electronic flight instrumentation system with pilot configurable multifunction displays, flight management system, weather radar, and electronic displays of maps and checklists. Acquisition of this glass cockpit trainer was a significant milestone in the modernization of the trainer fleet; it also marked USAF's return to a concept it had abandoned three decades earlier, Specialized Undergraduate Pilot Training (SUPT).

A shortcoming of the generalized flight training provided in UPT was that it did not provide student pilots with specialized skills and knowledge needed to smoothly transition to the large transport and tanker aircraft that constitute one third of the USAF fleet. UPT's single training track required all students to master the physical and cognitive challenges of high speed, dynamic flight in the T-38, an aircraft that handles like a fighter. This demanding training program emphasized aerobatic maneuvers and formation flying--skills that satisfy the training needs of students selected for assignments in fighter or attack aircraft. The aerobatics and close formation flight stressed in T-38 training were superfluous for students destined to fly multiengine, multicrew airlifters and tankers.

Under SUPT, students are assigned to one of two specialized training tracks at the completion of primary flight training. Students in the bomber-fighter (BF) track enter advanced training in the T-38. Students in the airlift-tanker (AT) track enter advanced training in the T-1. Training in the AT track emphasizes low-level navigation, simulated air refueling, simulated airdrops, and crew and systems management, mission areas far less visceral and much less dynamic than those emphasized in the BF track. The last UPT class entered training in March 1996. By March 1997, SUPT will completely replace single track UPT (HQ AETC/XOTI, personal communication, 1 April 1996).

USAF's goal of infusing the trainer fleet with current technology aircraft has resulted in decisions to replace the aging T-37 and to upgrade T-38 avionics to contemporary standards. The aircraft chosen to replace the T-37 is the Beech Mk II, known as JPATS (Joint Primary Aircrew Training System).

Student training in JPATS will begin in 2001. The aircraft will replace all T-37s in SUPT and Euro-NATO Joint Jet Pilot Training (ENJJPT) by 2009. JPATS' cockpit configuration is not yet finalized, but system requirements suggest JPATS will have the following equipment not present in the T-37 (2):

- Electronic ADI and HSI with pilot selectable display modes
- Electronic displays for all but standby instruments.
- Flight Director
- Global Positioning System (GPS) navigation
- Traffic Collision Warning system.

The primary flight training syllabus for JPATS will resemble that used today for T-37 primary training, similar in duration, flight hours, and training events (3).

A major avionics upgrade will replace existing T-38 instrumentation commencing in 1999. By 2004, all T-38A aircraft used in SUPT and ENJJPT will be upgraded to T-38C configuration (HQ AETC/XORF, personal communication, 11 September 1995). Upgrade plans include the following equipment (4):

- Pilot configurable multifunction displays with ADI and HSI modes
- Head-up display capable of providing primary flight reference data for instrument flight and simulated air-to-air and air-to-ground weapons employment
- GPS and inertial navigation systems (INS)
- Flight management system which allows entry and storage of flight plans, control of communications and navigation radios, and integration of navigation data
- Up-front controls to interface with the flight management system
- Simulated weapon delivery system
- Hands-on throttle and stick (HOTAS) control of selected communication and simulated weapons functions
- Traffic collision avoidance system

Modifications to the T-38 will allow USAF to include mission specific weapons delivery and tactics training in the BF advanced track. Current plans include extending BF track training by seven weeks to incorporate training now provided in a separate fighter fundamentals course (HQ AETC/XORF, personal communication, 11 September 1995).

The cockpits and equipment lists of the T-1A, JPATS, and T-38C are impressive. It is clear that the sophistication of operational weapon systems is cascading into student pilot training. Consequently, our student pilots will encounter complex avionics systems much earlier in their training than they have in the past.

3. HARDER, EASIER, OR JUST DIFFERENT?

The theme for this symposium asserts that complex cockpit systems pose considerable psychological problems for aircrew. It is possible that the T-1, JPATS, and upgraded T-38 will overwhelm some student pilots who could have performed well in less complex aircraft. Alternatively, it is possible that students who would have struggled through training in "round dial" aircraft will thrive in the new training environment. Certain flying and navigation tasks are, after all, easier to accomplish with the aid of contemporary avionics.

In a recent USAF study (5), SUPT instructor pilots identified poor position interpretation as one of the most pervasive deficiencies exhibited by student pilots. Throughout flight training, student pilots are required to perform flight maneuvers in a wedge-shaped block of airspace bounded vertically by specified altitudes and laterally by arcs and radials plotted from a radio navigation aid. Students learn to remain within this small area by reference to ground landmarks, and also by reference to navigation instruments. Straying outside of the practice area poses a risk of collision with aircraft in adjacent practice areas and generally results in an unsatisfactory grade. Failure to master this task is cause for elimination from training.

In the T-37, remaining within an assigned practice area requires recall of area boundaries from memory, reference to the altimeter, and interpretations of indications on three separate instruments to determine heading, distance and bearing to the navigation aid, and displacement from a desired radial. Assembling these discrete pieces of information into a complete spatial picture requires significant cognitive effort. Student pilots must perform this task while executing aerobatic maneuvers, turns, and course reversals which render normal spatial relationships of left, right, in front, and behind meaningless.

In the JPATS, the student need reference only two instruments to maintain position awareness: the altimeter and the HSI. The integrated HSI provides the student with a more intuitive depiction of position than the single function gauges in the T-37. GPS has the potential to offer the student pilot an even better spatial depiction that requires little interpretation. With either system, determining position within the practice area imposes less demand on the student's spatial abilities than the same task in the T-37.

In a similar fashion, GPS navigation and flight management systems can relieve student pilots of mental calculations of distance, speed, and time during enroute navigation. Introduction of a flight director display in primary flight training can reduce the demand for control input decisions during instrument landing approaches. Any number of examples can be cited to illustrate how advanced cockpit technology can reduce mental workload in routine flying tasks.

Learning to use the equipment in an advanced cockpit presents increased cognitive challenges of a different sort. Student pilots in the JPATS, T-1, and T-38C will need to know how to operate the sophisticated avionics at their fingertips. The number of systems in these aircraft and their multiple modes of operation demand that flight students acquire extensive systems knowledge. Students in the T-38 are provided three hours of academic instruction on current T-38 avionics (21). In contrast, T-1 students are given fifteen hours of academic instruction on the T-1's sophisticated avionics systems (22).

Concurrent with the acquisition of systems knowledge, student pilots will need to develop system management skills. A crucial skill for these aviators will be managing the quantity and format of information presented on multimode displays.

Whether advanced cockpit trainers will make pilot training more or less difficult remains to be determined. What is evident is that the introduction of advanced cockpit technology in UPT will result in a redistribution of pilot workload among different ability domains. Successfully flying an advanced cockpit training aircraft may depend less on spatial abilities than on acquisition and recall of declarative knowledge; less on the ability to manipulate quantitative information than on the ability to monitor multiple sources of data. Analyses of trainer aircraft and training syllabi used in primary and advanced training will be necessary to determine the human capabilities required for successful training performance. Such analyses would provide the essential direction for development of testing systems which would produce ability information for use in pilot selection.

4. CURRENT PILOT SELECTION PROCESSES

The concern that complex aviation technology may introduce psychological problems for aircrew is particularly relevant for pilot training. Such problems could result in loss of life and increased training costs. For aircraft currently used in UPT, operation costs are high. The cost per flying hour exceeds $700 for the primary trainer and $1,000 for the advanced trainer. The cost of an eliminee from pilot training varies from $50,000 to $350,000 depending on when elimination occurs in the training process. Since 1988, USAF UPT has produced on the average of one thousand pilots each year. Applicants to pilot training come from several different sources. Applicants are provided through the Officer Training School (OTS), the Active Air Force, the Air National Guard (ANG), the Air Force Reserve (AFRES), the Reserve Officer Training Corps (ROTC) and the USAF Academy. Recently about half of the applicants have been provided by the USAF Academy and the other half have been provided by ROTC. For the major sources of applicants, the selection rate is about 86 percent. The reason for the high selection rate is that individuals who apply for pilot training are carefully prescreened before their applications are submitted to selection boards. For ROTC, OTS, ANG, AFRES

and Active Air Force, applicants to pilot training are first selected for officer commissioning with reference to physical, education and ability minimums. After selection for officer commissioning, individuals who satisfy a second, higher ability minimum requirement are permitted to apply for pilot training and are considered by selection boards. Pilot selection decisions are based on leadership potential, educational achievement, physical fitness and ability based on both pencil-and-paper and computer-based ability testing. Notice that job sample testing in the form of either a simulated or actual flying exercise is not used for pilot selection decisions. The reason for this is that pilot selection by these sources is highly decentralized. Pilot testing takes place at over 100 sites at universities in the continental United States in addition to several other sites world-wide. Given the highly decentralized approach to pilot selection, the technical support costs associated with job sample testing by either actual aircraft or by a flight simulator, like the Canadian Automated Pilot Selection System, would be prohibitive. However, after the applicant pools are reduced to the subset of pilot selectees, selected individuals must complete flight screening in a single-engine, propeller driven, low-wing aircraft. Flight screening consists of 23 hours of flight instruction. The elimination rate is approximately 12%. Those who successfully complete flight screening proceed to jet training.

The USAF Academy uses a different procedure for pilot selection. Cadets who apply for pilot training must first pass a physical examination and job sample testing in the form of flight screening before they are considered by a selection board. Flight screening is similar to that used by the other sources. Pilot selection decisions are based on leadership potential, flight performance, educational achievement and physical fitness. The Academy is unique in that results from flight performance are considered for pilot selection decisions and that ability test scores do not appear to be given major consideration in the pilot selection process. This approach is warranted in view of the fact that information concerning cadets' flight screening performance and potential for success in pilot training is accumulated over the four-year duration of residency at the USAF Academy. In effect, the USAF Academy employs an assessment center approach to pilot selection. However, if an extended period of time is not available to obtain information concerning an applicant's potential for success as a pilot and if the pilot selection process is highly decentralized, as is the case for the other sources of pilot applicants, ability testing provides valuable information for pilot selection that has demonstrated value in reducing flying training attrition. In recent years, there have been important advances in the measurement of human abilities that will help improve pilot selection.

5. ABILITY MEASUREMENT

Advances in ability measurement that will improve pilot selection occur in two categories. The first category is defined as those that are feasible based on current technology and which could be implemented within the next 10 to 15 years. One possible advance in this category involves virtual reality computer technology. The second category is defined as advances that have already occurred and have been implemented within the last 10 to 15 years. There are three items in this category: improvements in ability measurement, improvements in test development approach and improvements in methods of test evaluation.

5.1 Future Advances

The advance suggested in the first category is based on currently available computer technology. Computer technology may help us solve difficult measurement problems. Even though leadership is a major criterion for pilot selection and an individual's ability to function as part of a team is the basic building block of military mission accomplishment, currently obtained indicators of an individual's leadership and team work skills are indirect and based on subjective judgment. One exciting advance in ability measurement that may emerge in the next 10 to 15 years could be based on virtual reality computer technology. Applicants to UPT may be tested in a virtual environment for the measurement of leadership and team work. Measurement could be based on an examinee's performance as leader while interacting with a standard cast of virtual team mates in a synthetic environment. Standard objectives and team interaction problems based on differences in the rank, gender, ethnicity, personality and ability of synthetic team members could be imposed as performance constraints for the pilot applicant. Individual differences in decision making, leadership and team work in the presence of such constraints would be the subject of measurement. Use of this technology could allow us to replace today's subjective ratings and intuitive judgments with objective measures of leadership and team work skills.

5.2 Recent Achievements

The second category of advances in ability measurement consists of achievements that have been accomplished over the last 10 to 15 years. The first occurred when ability testing with pencil-and-paper was supplemented with ability testing by computer. Advances in ability testing have paralleled those in aviation technology because both share computer technology. The USAF implemented computer-based ability testing for operational pilot selection in July of 1993. This change signaled a return to the measurement of psychomotor skills like that accomplished during and after World War II. In the early years of the USAF, measures of psychomotor skill were obtained by what was called apparatus tests. However, difficulties associated with standardizing measurement across tests of the same type eventually resulted in termination of apparatus testing. Computer-based testing offers a dependable

technology with which standardized measurement can be assured. The use of computer-based testing represents an improvement for pilot selection because it expands the breadth of measurement and provides unique ability information that independently contributes to the prediction of pilot training performance.

The second major advance in this category consists of the approach to test development. Historically, development of pilot selection tests was based on the independent efforts of different test development experts. Many useful and many useless tests were developed, but, because independent experts formed the basis of this approach, development and evaluation of tests was often unsystematic. The problem was the lack of a general theory to integrate test development and evaluation efforts. For USAF pilot selection research, a theory of learning ability structures the approach to test development. The theory suggests that pilot training success depends on individual differences in learning abilities. A broad taxonomy of human learning abilities has been proposed (24). The taxonomy can be represented as a matrix of rows and columns where columns represent verbal, quantitative, spatial and psychomotor abilities. Information processing theory suggests other cognitive abilities like working memory, processing speed, fact learning ability and procedural learning ability. These abilities are included as the rows in the matrix. Learning abilities are hypothesized to be represented at the intersection of rows and columns. This taxonomy structures test development so that we do not develop tests of simple verbal, quantitative, spatial and psychomotor abilities. Each of these abilities is considered an ability domain within which specific information processing abilities operate. The theory implies that acquisition of flying skills may not simply depend on spatial ability but rather spatial working memory and spatial processing speed. The same is true for the other ability domains. Domain specific working memory, processing speed, declarative learning and procedural learning ability operates to influence skill acquisition. Test development consists of producing multiple tests of each of these specific learning abilities. The important contribution represented by the taxonomy of learning abilities is that it serves as a source of hypotheses concerning individual differences and an integrating framework for the test development process.

The third major advance in ability testing has occurred because of advances in quantitative methods used for test evaluation. These advances allow statistical tests of hypotheses about the factorial composition of sets of variables. The approach is referred to as confirmatory factor analysis or covariance structure modeling and is accomplished by computer programs known as LISREL (23) or EQS (6). This advance allows us to test hypotheses concerning the factorial composition of ability tests and training outcome variables. As a result we have a better understanding of the general and specific factors actually represented by experimental ability tests and therefore can use available test time by avoiding duplication of tests that measure the same factors and by including tests which best represent the general and specific factors most highly related to pilot training outcomes. Confirmatory factor analysis has also allowed us to test hypotheses of the factorial composition of training outcome variables. As a result, we know training outcome variables that are typically available for test validation often under-represent the multidimensionality of the training performance domain. Training performance variables often used in validation studies over-represent what Campbell (7) refers to as job-specific tasks and under-represent other important dimensions of training performance including maintaining personal discipline, communication and motivation. The use of confirmatory factor analysis has clarified our understanding of the types of abilities we are measuring and limitations in the criteria used for validation studies. Consequently, we expect that future improvements in pilot selection will come from comprehensive studies that represent multiple dimensions of the training performance domain and pilot selection tests that provide information for a broad range of individual differences including cognitive, psychomotor and noncognitive attributes.

6. ANALYTICAL RESULTS

The primary objectives of test evaluation analyses are to determine the factorial relationship of new experimental tests to existing tests and the validity and incremental predictive utility provided by the new tests beyond that already provided by tests currently in use. In addition, causal model analyses have advanced our understanding of how individual difference variables influence training and job performance. Particular attention will be given to studies addressing:

(1) what is being measured in pilot selection tests,

(2) how ability and prior knowledge influence the acquisition of aviation knowledge and flying ability in training,

(3) examination of sex and ethnic group differences, and

(4) prediction of flying training performance and operational pilot performance (i.e., job performance).

Most of the studies that follow are focused on the two most widely-used USAF pilot selection tests, the Air Force Officer Qualifying Test (AFOQT) and the Basic Attributes Test (BAT). However, some attention is also given to several experimental "next-generation" computer-based tests.

6.1 What is Measured?

Air Force Officer Qualifying Test. The AFOQT has been used since 1957 for officer commissioning and pilot selection. New forms are developed about every seven years. The current form has 16 subtests that are combined into five operational score composites: Verbal, Quantitative, Academic Aptitude (Verbal + Quantitative), Pilot, and Navigator-Technical. The 16 tests are Verbal Analogies (VA), Arithmetic Reasoning (AR), Reading

Comprehension (RC), Data Interpretation (DI), Word Knowledge (WK), Math Knowledge (MK), Mechanical Comprehension (MC), Electrical Maze (EM), Scale Reading (SR), Instrument Comprehension (IC), Block Counting (BC), Table Reading (TR), Aviation Information (AI), Rotated Blocks (RB), General Science (GS), and Hidden Figures (HF).

In a recent confirmatory factor analysis, Carretta and Ree (17) demonstrated that the AFOQT has a hierarchical structure similar to other multiple aptitude tests (see Figure 1). The average correlation among the 16 subtests was about .44. General cognitive ability (g) was the higher-order factor. The residulized lower-order factors were verbal (V), math (M), spatial (SP) aircrew interest/aptitude (AI), and perceptual speed (PS). The proportions of common (i.e., explained) variance for *g* and specific factors found in the AFOQT were similar to that found in other multiple aptitude batteries. The proportion of common variance due to *g* was estimated to be 67%. The remaining common variance (33%) was distributed among the five residualized lower-order factors of verbal 11%, math 4%, spatial 4%, aviation interest/aptitude 9%, and perceptual speed 4%.

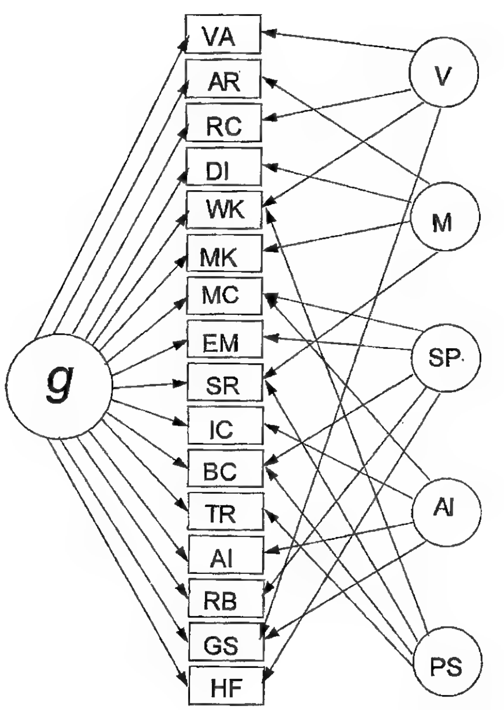

Figure 1. AFOQT Factor Structure

Basic Attributes Test and the Pilot Candidate Selection Method. The Basic Attributes Test or BAT is another important component in Air Force pilot selection. The BAT is computer-based and includes measures of psychomotor coordination, information processing speed, and attitudes toward risk. BAT scores contribute to a pilot selection composite known as the Pilot Candidate Selection Method or PCSM (9). The PCSM model combines the AFOQT Pilot composite with BAT scores and a self-report of flying experience in a regression-weighted equation to predict pilot training performance. PCSM scores have been shown to be related to probability of completing UPT (9, 10), number of flying hours needed to complete training (20), class ranking (10) and fighter qualification. PCSM has been used operationally by the Air National Guard as a component of their pilot selection procedures for over five years and was implemented by the Air Force in July 1993.

Ree and Carretta (27) studied the factorial complexity of the BAT psychomotor tests. The BAT psychomotor tests were administered to 354 Air Force enlisted personnel who had also completed a highly *g*-loaded battery of verbal and math tests.

Confirmatory factor analyses showed a hierarchical structure that included two higher-order and five lower-order factors (see Figure 2). Unexpectedly, a higher-order general cognitive factor influenced all scores, both cognitive and psychomotor. A higher-order psychomotor factor (PM) was found that influenced all psychomotor scores.

The five lower-order factors represented the cognitive constructs of verbal (V) and math (M) and the psychomotor constructs represented by the tests of Two-Hand Coordination (TH), Complex Coordination (CC), and Time Sharing (TS). The proportions of common variance accounted for by the higher-order factors were 39% for general cognitive ability and 29% for general psychomotor ability. The proportions for the lower-order factors were 10% for Two-Hand Coordination, 7% for Complex Coordination, 7 % for Time Sharing, 5% for verbal, and 3% for math.

The finding that both cognitive and psychomotor tests loaded on the higher-order general cognitive factor indicated that the BAT psychomotor tests measured, at least in part, *g*. The correlations between the cognitive and psychomotor tests and the finding of a general cognitive ability factor that included both cognitive and psychomotor scores may have been the consequence of the need to reason while performing the tests. The degree of *g*-saturation for the BAT psychomotor scores is consistent with Rabbitt, Banerji, and Szymanski (26). They found that "Space Fortress," a test that appears to require complex perceptual-motor ability, correlated with paper-and-pencil IQ tests about as well as paper-and-pencil IQ tests

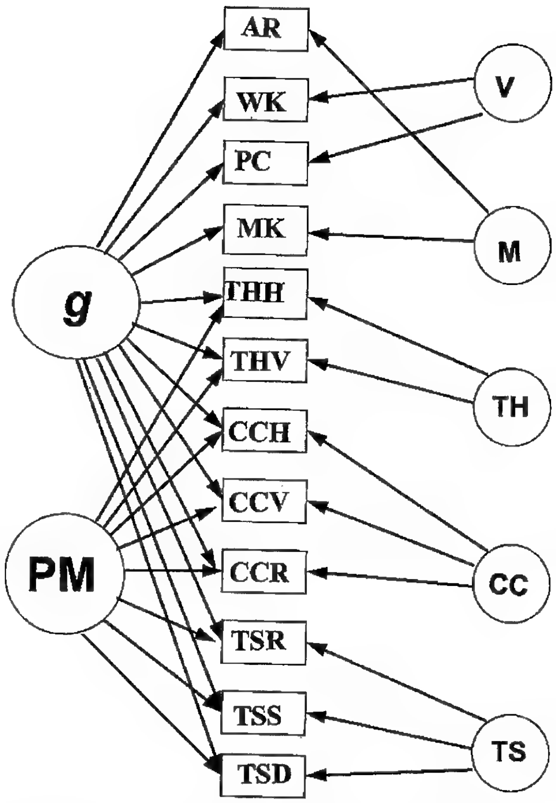

Figure 2. Structural Model of Cognitive and Psychomotor Ability

correlated with one another. Again, the need to reason and learn to apply complex rules may explain the findings of Rabbitt et al. (26).

6.2 How Does Ability and Job Knowledge Influence Skill Acquisition?

Path analysis is a technique that uses linear regressions to test specific hypotheses about relationships among a set of variables (see for example, (1). As in true experiments, inferences of causation depend on proper time sequence, covariance between the independent and dependent variables, and nonspuriousness of relationships. Ree, Carretta, and Teachout (28) investigated a causal model of the influence of *g* and prior pilot job knowledge (JK_P) on pilot job knowledge acquired during training (JK_{T1}, JK_{T2}, and JK_{T3}) and flying training work sample performance (WS_1 and WS_2). The model is displayed in Figure 3. The latent variables (*g*, JK_P, JK_{T1}, JK_{T2}, JK_{T3}, WS_1, and WS_2) and path model were estimated using the EQS program (6). General cognitive ability (*g*) was estimated from the AFOQT verbal and math subtests and prior pilot job knowledge (JK_P) was estimated from the AFOQT Instrument Comprehension and Aviation Information subtests. Job knowledge acquired during training was estimated from academic grades during early (JK_{T1}), middle (JK_{T2}), and late (JK_{T3}) phases of ground school during UPT. Work sample performance was estimated from check flight grades in the T-37 (WS_1) and T-38 (WS_2).

As with prior research, the measure of *g* showed a much stronger causal influence on training performance than did prior job knowledge. They found that *g* affected pilot training performance mostly through its influence on the acquisition of

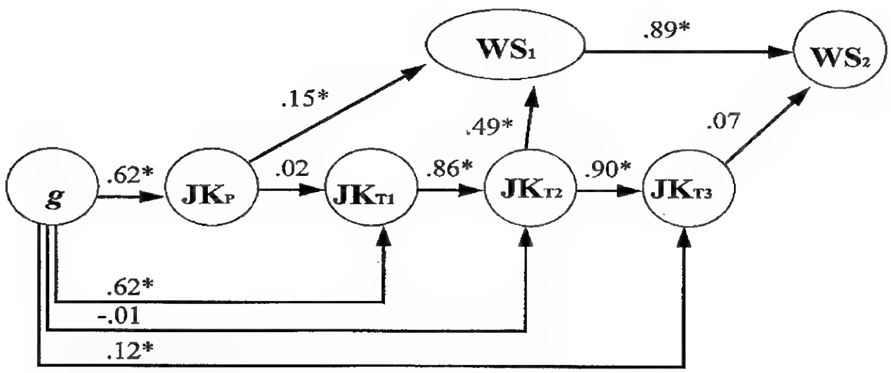

Figure 3. Factor Model of Pilot Training

job knowledge. Prior job knowledge directly influenced flying work sample performance early in training, but did not have much influence on the acquisition of additional pilot knowledge during training. Early training knowledge led to the acquisition of later training knowledge and flying performance. Early flying performance strongly influenced later flying performance.

6.3 Examination of Sex and Ethnic Group Differences

The investigation of sex and ethnic group differences is an important consideration in the evaluation of personnel measurement instruments. It must be demonstrated that the tests do not lead to adverse impact and are not differentially predictive for different subgroups tested. Adverse impact occurs when members of one subgroup are disproportionally disqualified compared to members of another subgroup on the basis of test performance. Differential prediction would exist if the test were valid for one group of pilot trainees and not valid for some other group of pilot trainees. U.S. Government guidelines prohibit the use of personnel selection tests that display adverse impact or test bias. Evidence of differential prediction is accepted as evidence of test bias.

Carretta and Ree (16) examined the AFOQT factor structure for 269,968 male and female officer applicants from five ethnic groups. Despite group mean score differences on the 16 subtests, the Carretta and Ree (17) model (see Figure 1) showed good fit for all groups and the proportions of total and common variance accounted for by g and the five lower-order factors were similar for men and women and for Whites, Blacks, Hispanics, Asian-Americans, and Native-Americans. These findings were interpreted as evidence of near identity of cognitive structure for sex and ethnic groups.

Carretta (11) examined sex and ethnic group differences on the AFOQT composites and subtests for Air Force officer applicants and pilot trainees. Results showed that large mean score differences in applicant samples favoring males and Whites were substantially reduced among pilot trainees. The reduction in group differences in the pilot sample was interpreted as being the direct result of the selection process. Despite differences in AFOQT mean performance, there was no evidence of differential validity for the groups. When group differences in predicted pilot training completion were observed, performance was overestimated for the minority group (females or ethnic minorities) relative to the majority group (males or Whites). The observed differences in intercepts were reduced or eliminated when the regression equations were adjusted for unreliability. No prediction bias was observed against the minority groups.

Recently, Carretta and Ree (18) tested the causal model of pilot training (Figure 3) on separate samples of male and female pilots. Results were similar for males and females. However, the direct and indirect influence of g on flying performance was stronger for females than for males. Additionally, the relationship between prior job knowledge and flying performance was stronger for females than for males. Consistent with Ree et al. (28), the influence of early flying skills on later flying skills was very strong for both sexes.

6.4 What is Predictive?

Air Force Officer Qualifying Test. Carretta and Ree (15) examined the validity of the 16 AFOQT subtests against five pilot training criteria based on performance on academic tests, daily training flights, and check flights. The rank correlation of the g-loadings of the AFOQT subtests with their average validity for predicting these five pilot training criteria was .62. The higher the g-loading of the subtest, the more valid it was for predicting the pilot training criteria.

Olea and Ree (25) compared the validity of g, specific abilities, and specific knowledge for predicting performance in samples ranging from about 1,800 to 3,900 pilot trainees. Using unrotated principal components, measures of g, specific abilities, and specific knowledge were estimated from the AFOQT. The flying training criteria included academic grades, flying work samples (e.g., landings, loops, and rolls), and an overall performance composite. Regression equations were used to evaluate the predictive utility of g and specific abilities and knowledge for each of the criteria. General cognitive ability was the best predictor of each of the pilot criteria, while specific abilities and knowledge contributed little. The average validity for g was .316 across all criteria. The average incremental validity for the specific abilities and knowledge was about .098. Little incremental validity beyond g was found for the flying work sample (.095) or the composite performance criteria (.089). Results suggested that the incremental validity may have been due to specific knowledge content about aviation (i.e., aviation principles, controls, and instruments) rather than specific cognitive abilities (i.e., verbal, quantitative, spatial, or perceptual speed). Prior pilot job knowledge was the source of the incremental validity.

Pilot Candidate Selection Method. Several studies have demonstrated the validity of PCSM scores against various pilot training criteria including probability of completing jet training (9, 10), number of flying hours needed to complete training (20), class ranking (10) and fighter qualification. High PCSM scores are associated with greater probability of completing training successfully, fewer flying hours needed to complete training, higher class ranking, and greater likelihood of being evaluated as fighter-qualified.

An analysis of 479 Air National Guard pilot trainees tested on a pre-operational version of PCSM showed a strong relationship between the composite score and UPT flying performance. These results are shown in Figure 4. For trainees who tested in the bottom 25% on PCSM (i.e., score between 1 and 25), there was about a 20% failure rate due to flying training deficiencies

(FTDs). For those who tested in the top 25% on PCSM (i.e., score between 76 and 99), the FTD rate was about 2%. PCSM was also useful for predicting class ranking for these student pilots. For those with PCSM scores between 1 and 25, only 1% ranked in the top 10% of flying training graduates (distinguished graduates or DGs), while for those with scores between 76 and 99, about 25% ranked in the top 10% of graduates.

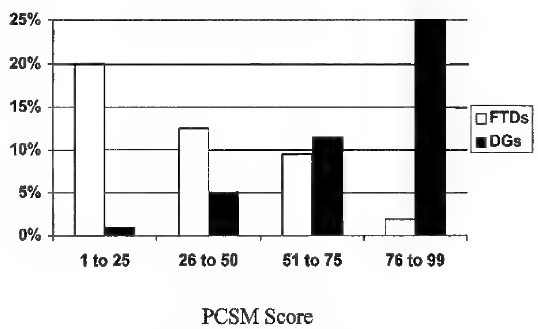

Figure 4. Training Performance by PCSM Score

Duke and Ree (20) examined the relationship between PCSM score and the number of hours needed to acquire skills in USAF UPT for a sample of 1,082 graduates. This was done to investigate the validity of PCSM for predicting training time and was not conducted to recommend revisions in the training syllabus. The criterion, "extra flying hours," was computed by subtracting each student pilot's cumulative flying hours from the sample mean. The correlations (corrected for range restriction) between PCSM score and early (i.e., T-37) and later (i.e., T-38) training flying hours were -.206 and -.270, respectively. These results demonstrated that pilot training graduates with higher PCSM scores required fewer flying hours to acquire selected flying skills. Therefore, selecting pilot candidates with high PCSM scores would result in high quality candidates who quickly acquire flying skills.

Carretta and Ree (14) examined the validity and incremental validity of the PCSM components in a sample of 678 pilot trainees. The following correlations were observed with passing-failing pilot training: AFOQT Pilot composite .17, BAT psychomotor .15, information processing .06, attitude toward risk .10, and previous flying experience .17. When all scores were used in a common equation, the BAT and flying experience scores incremented the validity of the AFOQT from .17 to .30. These correlations could not be corrected for range restriction due to linear dependence between the Pilot composite and subtests of the AFOQT. These uncorrected correlations should be considered underestimates of the population values.

Recently, two studies examined the validity of several experimental cognitive-components-based tests for predicting pilot performance. These studies, conducted with pilot trainees (12) and active duty F-15 pilots (13), identified several promising pilot aptitude tests.

Carretta (12) examined the predictive validity of 45 computer-based cognitive tests for 1,855 USAF pilot trainees. Correlational analyses showed that 21 of the 45 tests were related significantly to graduation/elimination from pilot training. Tests with verbal content were less likely to be valid (2 of 12 tests) predictors of flying training outcome than were those with either numerical/quantitative content (8 of 15 tests) or spatial content (11 of 18 tests). These findings were consistent with a recent validation of the AFOQT against pilot training academic and flying grades (15).

Carretta et al. (13) examined whether situational awareness (SA) in USAF F-15 pilots could be predicted from measures of cognitive ability, psychomotor ability, personality, and flying experience. One hundred seventy one active duty F-15 pilots completed a computer-based cognitive, psychomotor, and personality test battery. Supervisor and peer ratings of SA were collected. F-15 flying experience (i.e., number of F-15 flying hours) was the best predictor of supervisor and peer ratings of SA. After controlling for F-15 experience, measures of general cognitive ability based on divided attention, spatial reasoning, and working memory were predictive of SA. Psychomotor and personality measures were not predictive.

6.5 Current Research and Development Directions

As previously noted, the AFOQT has been used, evaluated, refined, and revised by the USAF since 1957. In contrast, the BAT and PCSM are relative newcomers. As a result, personnel measurement issues regarding factor structure, test-retest performance, the role of psychomotor skill in pilot performance, sex and ethnic group differences, etc. have not been completed for the BAT and PCSM. Several efforts are in progress to address these issues.

A second line of research involves the development and validation of a next-generation computer-based pilot selection test battery. Several of the tests that showed utility in the Carretta (12) and Carretta et al. (13) studies are undergoing advanced development and evaluation for possible operational use in future pilot selection batteries. Additional test development efforts are examining the relationship between general and specific cognitive abilities and an expanded range of psychomotor abilities (19). These efforts are expected to lead to advances in the measurement of pilot aptitude and a better understanding of the role of general cognitive ability, specific abilities, and job knowledge in pilot skill acquisition.

7. CONCLUSION

Although modern aviation technology provides tremendous advantages, there is concern that complex aircraft cockpit systems may introduce psychological problems for aircrew. This concern is particularly relevant for pilot training. Over the thirty years between 1962 and 1992, undergraduate pilot training changed relatively little. However, in the past three years training has changed significantly and will change dramatically over the next ten years. These changes give us cause to question whether the standards and expert judgment applied in current pilot selection processes will provide us with pilot candidates capable of succeeding in the next decade's flying training programs.

Concurrent with changes in training, there have been advances in the measurement of human abilities that will help improve the pilot selection process. Advances occurred when ability testing with pencil-and-paper was supplemented with ability testing by computer. The use of computer-based testing represented an improvement for pilot selection because it expanded the breadth of measurement and provided unique ability information that independently contributed to the prediction of pilot training performance. Advances have also occurred in test development. A taxonomy of learning abilities has been proposed which serves as a source of hypotheses concerning individual differences and integrates the test development process. The final advance in ability measurement has occurred in the area of test evaluation. Confirmatory factor analysis has allowed us to fine tune pilot selection systems and identify limitations in pilot training criteria used for test validation. As a result, future improvements in pilot selection will come from comprehensive studies that represent multiple dimensions of the training performance domain and pilot selection tests that measure a broad range of individual differences including cognitive, psychomotor and noncognitive attributes.

Research has provide evidence of the utility of these advances. Confirmatory factor analyses of the Air Force Officer Qualifying Test have indicated that it is factorially homogeneous and mostly measures general intelligence. Confirmatory factor analyses of tests of general intelligence and psychomotor measures from the Basic Attributes Test indicate that computer-based testing expands the breadth of measurement and provides unique ability information for the pilot selection process. Validation studies demonstrate that when psychomotor measures and an indication of flying experience are added to measures of general intelligence, validity almost doubles in magnitude. Finally, analyses of a broad range of abilities related to success in current undergraduate pilot training indicate that tests of verbal abilities were less likely to be valid than tests of quantitative and spatial abilities. This finding is particularly interesting because of the baseline it establishes for the future. Preliminary analyses of advanced training systems suggest that there may be a redistribution of pilot workload among different ability domains. The ability to recall declarative information concerning systems operation and the ability to monitor multiple sources of information may eclipse spatial visualization and quantitative abilities, in terms of relative importance. The possibility of a shift in the relative emphasis of abilities required for successful pilot training is extremely important for pilot selection and training. Comprehensive task analyses of modern trainer aircraft and training syllabi used in primary and advanced training will be necessary to reveal the human capabilities required for successful training performance and guide revisions of pilot selection systems to assure correspondence between the standards for pilot selection and demands of pilot training.

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ASSESSMENT OF ANTHROPOMETRIC ACCOMMODATION IN AIRCRAFT COCKPITS AND PILOT BODY SIZE SELECTION CRITERIA

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INTRODUCTION

Designing high-performance aircraft cockpits to accommodate the wide range of body sizes existing in the US population has always been a difficult problem for Crewstation Engineers. To alleviate this problem, the US Air Force restricts the range of body sizes allowed into flight training, and then develops aircraft design standards and specifications around that reduced population. Limiting the size of the aircraft crewstation (and, therefore, the aircraft) should also reduce the cost and improve the performance of the aircraft.

Our current regulation, AFI 48-123, "Medical Examination and Standards," dictates that USAF pilot candidates must be between 162.6 and 195.6 cm in Stature, and between 86.4 and 101.6 cm in Sitting Height. Figure 1 shows these limits superimposed over the US male military population. Those outside the box are ineligible for flight training. Six percent of this male population is too small to enter flight training. These limits have been in place for many years; however, the USAF is currently considering relaxing these requirements in order to make flight training more accessible to women. This is being considered because the current regulation prevents roughly 55% of female military members from entering flight training (Figure 2).

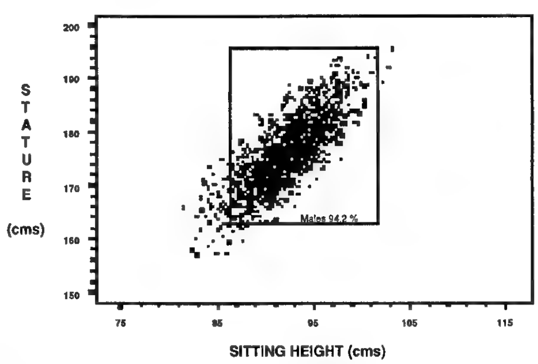

FIGURE 1
Effect of Body Size Limits on Male Population

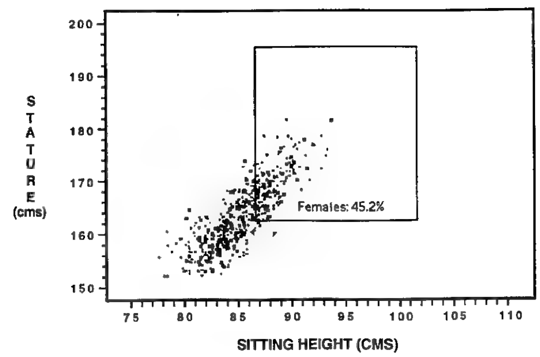

FIGURE 2
Effect of Body Size on Female Population

The vast majority of these two samples are from Americans of European descent. The effect of these restrictions is even more severe on other racial/ethnic groups. Figures 3 and 4 show the effect of these restrictions on African-American and Asian-American males. Eighteen and 20 percent of these populations are outside the entrance requirements. Figures 5 and 6 show the effects of the regulation on African-American and Asian-American females. Eighty-three percent of these populations are outside entrance requirements. These charts illustrate how body size entrance requirements can have radically different effects when there is a demographic change in the pilot population. The inclusion of women pilots in combat aircraft roles is one of several examples of such a demographic shift.

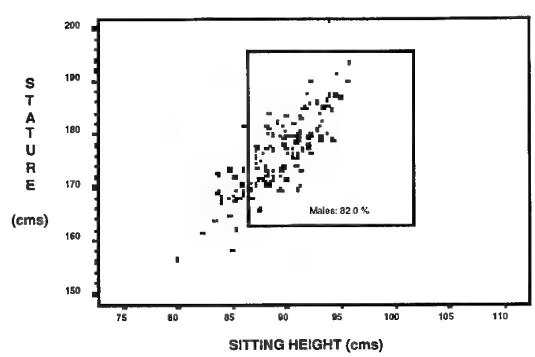

FIGURE 3
Effect of Body Size Limits on African American Male Population

Paper presented at the AMP Symposium on "Selection and Training Advances in Aviation", held in Prague, Czech Republic, in May 1996, and published in CP-588.

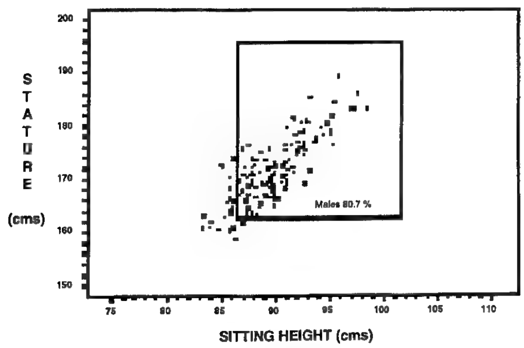

FIGURE 4
Effect of Body Size Limits on Asian American Male Population

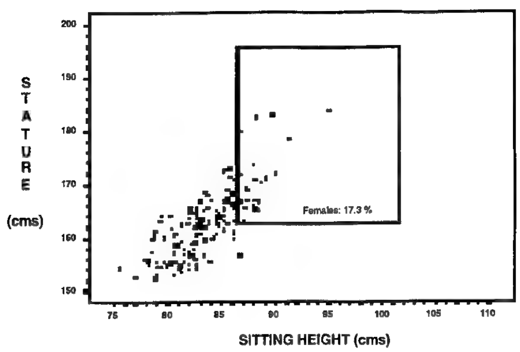

FIGURE 5
Effect of Body Size Limits on African American Female Population

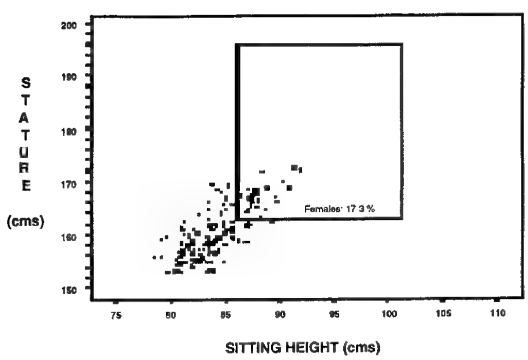

FIGURE 6
Effect of Body Size Limits on Asian American Female Population

Because of the restrictive nature of our pilot selection criteria, and their effect on the careers of female military members, the decision was made to design our newest training aircraft (the Raytheon Mark II) to accommodate a much wider range of body sizes. This aircraft was designed to accommodate a pilot with a Sitting Height as low as 78.7 cm and a Stature as low as 147.3 cm. It is anticipated that this increased range of body sizes will be the requirement for future aircraft designed for the military as well. The problem is, the anthropometry of the pilot population and design requirements for aircraft already in use by the USAF have closely paralleled each other. An increase in the size range of the pilot population of this magnitude raises questions about the aircraft to which these small people can be assigned after flight training. A change in pilot selection criteria will necessitate a very close examination of accommodation in existing aircraft to determine if pilots with the new range of body sizes can safely operate systems that were designed for a very different population.

COCKPIT DESIGN

Prior to 1990, body size variability was usually incorporated into cockpit design by performing anthropometric surveys on the existing pilot population and then using summary statistics from those surveys as design requirements for new aircraft (Zehner, Meindl, and Hudson 1993). On the small end of the design range, 5th percentile values for critical body dimensions were used as minimum design points; on the large end, 95th percentile values were used. Figure 7 shows the portion of the existing pilot population which meets these 5th to 95th percentile criteria. Members of the population that were smaller than the minimum design values are expected to "stretch" in order to be accommodated. Those larger than the maximum design values may find themselves cramped, and may have to "squeeze" to be accommodated.

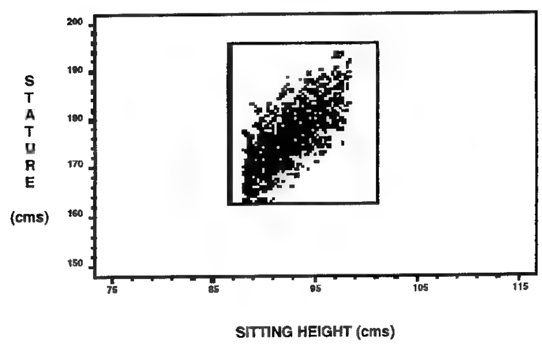

FIGURE 7
5-95 Percentile Design Population With Body Size Limits

Figures 8 through 12 show examples of accommodation problems which are typically encountered by individuals outside the 5th and 95th percentile limits.

FIGURE 8 Lack of Overhead Clearance

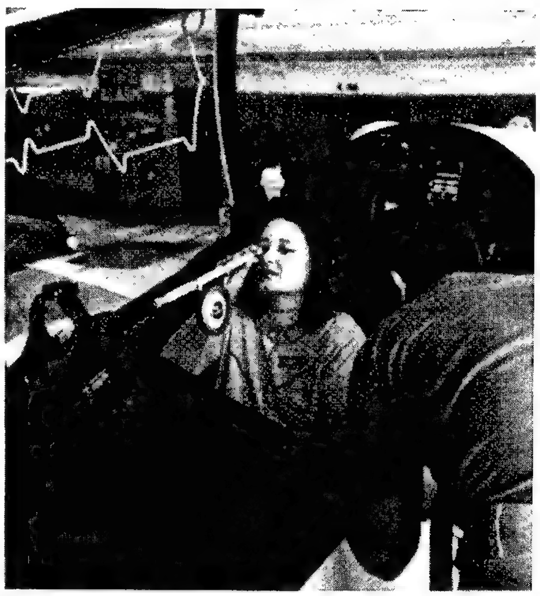

FIGURE 9 Minimal Over the Nose Vision

FIGURE 10 Difficulty reaching controls

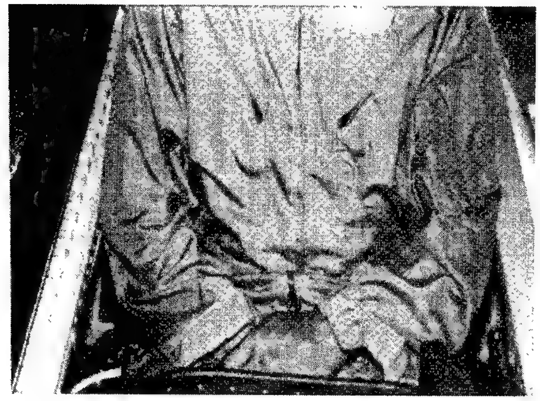

FIGURE 11 Minimal Shoulder/Elbow clearance

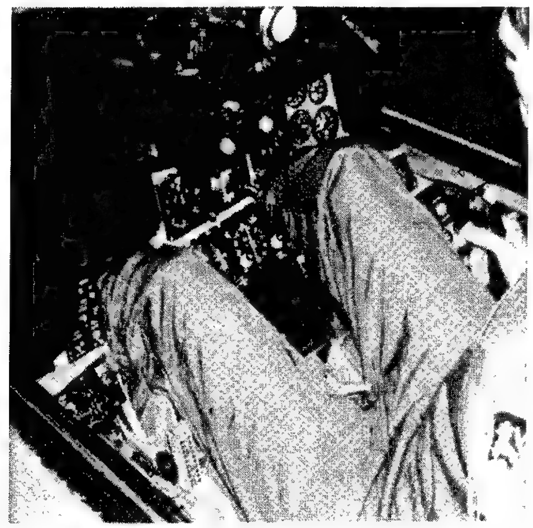

FIGURE 12 Inadequate Shin Clearance

While a relatively small percentage of the current pilot population experience these problems, it is expected that the problems faced by small pilots will become more prevalent in the near future due to the inclusion of women pilots in combat aircraft. In addition to the large portion of the female population being excluded from entering flight training, those that meet body size entrance requirements may also face high rates of accommodation problems.

That is because the 5th and 95th percentile values to which most existing aircraft were designed, were based on samples taken from the male pilot population of the time period. While female pilots must meet the same body size entrance requirements as male pilots, Figure 13 shows that up to 24% of the female pilot population falls below the male pilot 5th percentile value for Sitting Eye Height (related directly to vision over the nose of the aircraft). Figure 14 shows roughly 15% are smaller for leg lengths (related to ability to operate the rudder pedals). While stretching to be accommodated may be possible on one of these parameters, attempting to simultaneously stretch out the legs to reach the rudders while also trying to stretch up to see out of the aircraft, is a very difficult feat to perform while landing. To do so may put these individuals at risk

for mishap due to their inability to reach controls and adequately see out of the aircraft.

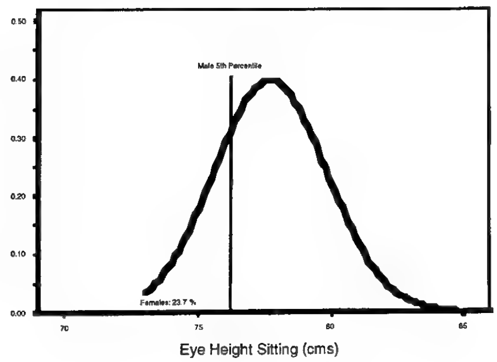

FIGURE 13
Female Eye Height Sitting Distribution

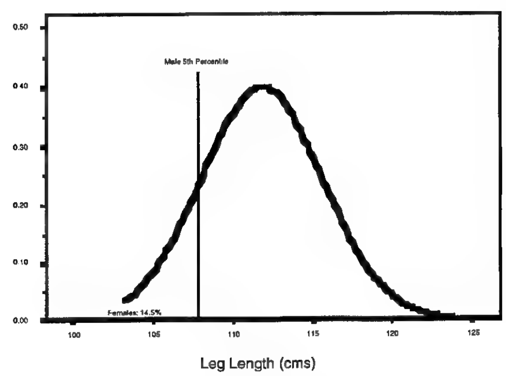

FIGURE 14
Female Leg Length Distribution

COCKPIT EVALUATION METHODS

To avoid pilot size-cockpit size mismatch, a set of evaluation procedures is being used to assess the anthropometric accommodation limits of cockpits. Accommodation in this instance is defined as the ability: to adequately see, reach, and actuate controls; to have external visual fields so that the pilot can see to land, clear for other aircraft, and perform a wide variety of missions (ground support/attack or air to air combat); and finally, to allow the pilot to safely escape the cockpit in an emergency.

Functional Requirements

The key to evaluating cockpit anthropometric accommodation is dictated by the "functional requirements." The accommodation definition in the preceding paragraph must be cast in terms of pass/fail criteria beyond which it is not safe to operate the aircraft. The question becomes, "Which controls must be reached with locked inertial reels," or "Which controls must be reached in an out-of-control situation where the pilot has limited mobility?" The answer would certainly include the ejection handle, the operational range of stick, throttle, and rudder, but should other controls also be included? How much must the pilot see in order to land safely? In a recent aircraft procurement, the US Air Force used a specific requirement that "the pilot must be able to see and track the touchdown point from approach through final flare." Flight tests were set up using small pilots. They lowered their seat while shooting an approach until they could barely see the touchdown point. When the flight test was complete, that angle of "over the nose vision" was measured and used as the pass/fail criterion for external vision. Many other areas of accommodation, such as the necessary amount of overhead or escape clearance space, must be quantified. The specific functional requirements (which will be used in the subsequent anthropometric evaluation) must be determined by consensus of the users of the system. A number of aspects of accommodation must be addressed, and the final pass/fail criteria must be defensible since they will be used to eliminate people from flight training eligibility.

Anthropometric Evaluation

Once the functional requirements are set, the anthropometric portion of the evaluation proceeds in order to determine the entire range of body sizes which are able to safely operate the aircraft. In a very real way the test subjects are used as human "tools" in the measurement process. Their size, position, and posture within the aircraft, and their abilities to perform tasks (for example, to reach to a control), allow measurement of how far they exceeded or missed a particular functional requirement. Gathering data in this manner permits extrapolation through regression analysis to other body sizes and types and eventually allows the location of the desired body size limits.

Seven aspects of accommodation are currently being examined: 1) overhead clearance, 2) operational leg clearances, 3) control stick/wheel operational clearance, 4) ejection clearances, 5) rudder pedal operation, 6) visual field, and 7) hand reach to controls. Each of these areas is directly affected by the body size of the pilot. The height of the pilot's eye in the cockpit determines the amount of available vision, the length of the pilot's arm and height of the shoulder affect the ability to reach and actuate controls, and leg length affects reach to rudders. The multivariate nature of human body proportions must be kept in mind when gathering and applying these data. The largest legs in a population do not necessarily come on the same individual as the largest Sitting Height. Individuals with very large legs and a short Sitting Height may in fact have to fly with the seat full up in order to see over the nose of the aircraft. This may put their shins very close to the forward instrument panel. Seat position obviously affects everything. By moving the seat up, the pilot with a short torso and short legs, may see the ground better, but is now further away from the rudders and controls. The approach taken in these procedures is to use a number of fully equipped test subjects of various sizes in a wide range of seat adjustment positions performing the tasks developed

in the functional requirements list to determine body size limits.

Sample size should be as large as possible, because several subjects with the same arm length can have different capabilities of reach, depending on his/her other body dimensions. The width of the subject's shoulders is important because of interference with the restraint system during a reach to a control. Subjects with wide shoulders have greater reach capability. The depth of the chest also can have an effect because of fit of the restraint system. It may be tighter on a thick chested pilot and restrict forward movement. Therefore, if only one subject is used in the evaluation of reach, or any other aspect of accommodation, the results will only be relevant to that particular individual. Such data cannot be trusted to be representative of pilots "of a similar size" in the using population. In these procedures, we have used as few as four and as many as twenty test subjects for each procedure. When regression analysis is used, as many subjects as possible should be evaluated.

To demonstrate how these data can be used, consider the following example:

A pilot candidate has anthropometric dimensions of Sitting Eye Height = 71.1 cm, Leg Length = 108 cm, Sitting Shoulder Height = 52.8 cm, and a Thumb-Tip Reach = 68.6 cm. Will this same person be accommodated in the T-37 aircraft? Since the functional requirements for the T-37 are unknown, the following are provided for this example.
1) Over the Nose Vision must be at least 9 degrees.
2) Full rudder pedal deflection must be accomplished while holding the toes on the brakes.
3) The most difficult reach which <u>must</u> be made with locked inertia reels is to the Canopy Jettison T-Handle.

The following charts show how the techniques described above can be used to assess accommodation for that individual.

First, the Over the Nose Vision capability of this person must be checked. Figure 15 illustrates that a person of this size sitting in the T-37 aircraft can see between 2 degrees and 9 degrees depending on seat position. Since the vision requirement is 9 degrees, this person passes but must position the seat full-up for the remainder of the evaluation.

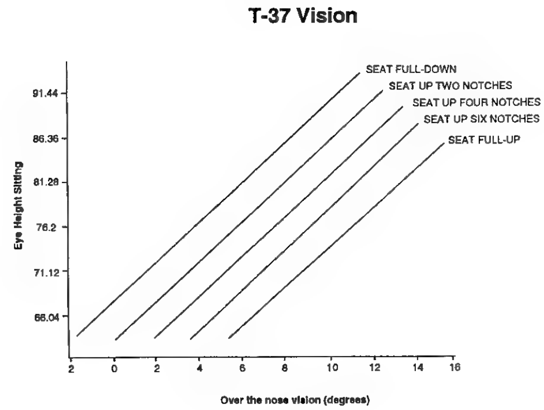

FIGURE 15

Next, by looking at the full-up seat position in Figure 16, we see that the pilot's legs must be at least 107.4 cm long to achieve full rudder throw. The example person again passes.

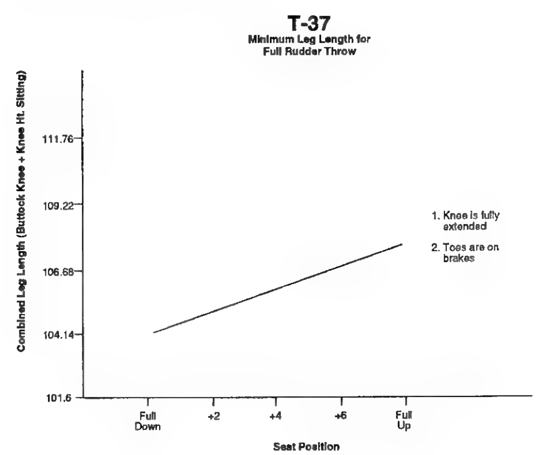

FIGURE 16

Finally, we locate our pilot's Shoulder Height on Figure 17, and follow it to the full-up seat position. The required Thumb-Tip Reach would be 68.1 cm. Once again the pilot passes.

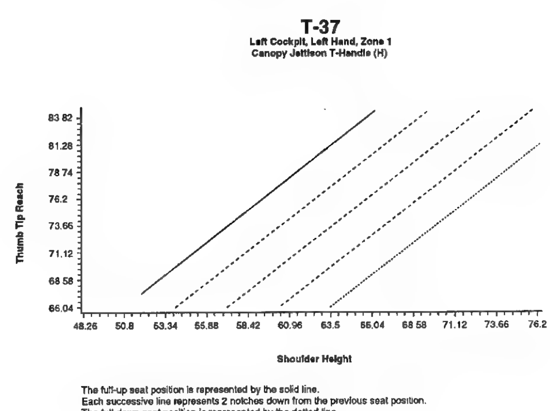

FIGURE 17

If these three functional requirements were the only ones necessary for a small pilot to accomplish, our example pilot could be accepted into this aircraft, but only passes by a small amount. The next step would be to determine what other aircraft this person must fly in order to determine if follow-on training aircraft will accommodate this body size, and if there are other fleet aircraft to which this pilot could be assigned after flight training.

CONCLUSION

The USAF has typically evaluated aircraft prior to purchase in order to assure that all of its pilots will be accommodated. However, since there is a possibility that the body size of the pilot population will be changing, the question becomes: what are the absolute limits for body size which define who can or cannot fly a particular aircraft?

The procedure described above can give a reasonable answer to this question. As with nearly all data on human capability, it will not be an exact prediction of a specific individual's performance. There is too much variability in human performance data. The data will, however, give a good approximation of the ability of a group of individuals of similar body sizes to be accommodated. Actual fit checks in an aircraft may still be necessary for individuals who are on the border between passing and failing.

By defining accommodation in quantitative terms, it will also be obvious where accommodation problems occur. Once data have been gathered on a particular aircraft, it may be possible to fix the problems. If rudders are unreachable for a large number of small pilots, perhaps the rudder carriage adjust could be changed so that the pedals are easier to reach. It may also be possible to relocate hand controls to make them more accessible.

Finally, if an older aircraft had been previously measured, was scheduled to be upgraded, and had changes proposed for the crewstation layout, these data could be used to assess the effects of the changes on the ability of the pilot population to operate the aircraft safely.

In conclusion, if pilot body size selection criteria are to change, the changes must be based on the body size limits imposed by all the aircraft in the fleet. This process should prevent individuals from being assigned to aircraft which they cannot safely fly.

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CHARACTERISTICS OF FEMALE AND MALE USAF PILOTS: SELECTION AND TRAINING IMPLICATIONS

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SUMMARY

The determination of psychological fitness to fly is complicated, particularly when attempting to extrapolate what little we know about male aviators to women. New training needs, for both women and men, may arise as the number of a country's female aviators increases. The large numbers of aviators in the United States Air Force (USAF) enable it to do research that may be instructive to other, smaller, air forces.

INTRODUCTION

Since AGARD considered the topic of women in military aviation in April 1990, the United States has rescinded the combat exclusion clause and consequently, the USAF now officially allows women to potentially engage in aerial combat. The Defense Women's Health Research Program (DWHRP) is funded by the United States Congress, which directed researchers to study the needs of women in military service. "Assessment of Psychological Factors in Aviators" (APFA), supported by the DWHRP, did not include participants from fighter aircraft. Many of the participants, although assigned to noncombat aircraft, vigorously maintained they were exposed to enemy fire while flying during the Persian Gulf War. They did not, however, have the opportunity to return fire. Furthermore, they did not have the relative peace of mind of sitting in an ejection seat; often they were also flying with thousands of pounds of fuel to refuel other aircraft.

TEXT

Women currently flying United States Air Force (USAF) aircraft were selected using methods developed for men (18). The structure of the paradigm of the "Right Stuff" (21) rests on a male foundation. Some criticize the research conducted to date (or perhaps *not* conducted) and the resulting selection techniques. Calls for better selection and screening techniques are older than the USAF, ranging from a 1940 United States War Department Technical Manual (20) to a 1995 Armstrong Laboratory Technical Report (2). The Adaptability Rating for Military Aviation (ARMA), a semi-structured interview conducted by base-level flight surgeons, is generally felt to be inadequate and is consequently not consistently administered (19).

Many selection efforts have focused on *select-out* concerns, identifying and eliminating those candidates with obvious psychiatric illnesses. Using psychological tests developed in the clinical arena, however, may lead to inflated estimates of psychopathology when used with aviators (8). It may be more productive to develop *select-in* procedures, identifying the most promising candidates (9). A ten-year follow up of student pilots (17) revealed very few significant differences in personality between successful and unsuccessful pilots when compared on clinical tests. In any case, there is likely more than one successful pilot type (13, 14, 15), with gender perhaps not being a significant variable (12).

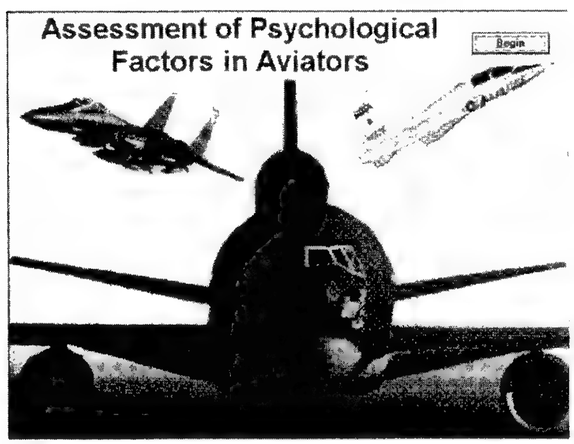

Figure 1. First screen of computerized APFA battery

This work was supported by the U.S. Army Medical Research and Materiel Command.

Opinions, interpretations, conclusions and recommendations are those of the author and are not necessarily endorsed by the U.S. Army.

The investigators adhered to policies regarding the protection of human subjects as prescribed by 32 CFR 219 and Subparts B, C, and D.

Paper presented at the AMP Symposium on "Selection and Training Advances in Aviation", held in Prague, Czech Republic, in May 1996, and published in CP-588.

Do female pilots bring different intellectual skills and personality styles into the cockpit? APFA solicited data within flying squadrons from non-medically referred USAF pilot volunteers. One hundred and fourteen (50 women, 64 men) fully qualified USAF pilots currently assigned to crewed aircraft took the Multidimensional Aptitude Battery (MAB; 4, 5), an intelligence (IQ) test. The MAB is presented in a multiple choice format as 10 seven-minute subtests. The Armstrong Laboratory helped computerize its administration; this version equates well with the paper-and-pencil version (16).

Multidimensional Aptitude Battery (MAB):

Verbal IQ - Crystallized ability (results from interaction with the culture)

Information - Fund of knowledge, long-term memory
Comprehension - Ability to evaluate social behavior
Arithmetic - Reasoning and problem-solving ability
Similarities - Flexibility, adjustment to novelty, abstract thought, long-term memory
Vocabulary - Openness to new information, capacity to store, categorize and retrieve words and verbal concepts previously learned

Performance IQ - "Fluid" ability (independent of education and experience, capacity for learning and problem solving)

Digit Symbol - Adaptation to a new set of demands, learning coding, performing visual-motor tasks
Picture Completion - Identifying important missing elements in a picture, knowledge of common objects
Spatial - Ability to visualize abstract objects in different positions
Picture Completion - Ability to identify a meaningful sequence, social intelligence and insight into others' behavior
Object Assembly - Visualization skills and perceptual analytical skills needed to identify a meaningful object from a left-to-right sequence

Full Scale IQ - General aptitude (compilation of all subtests).

Participants also took the NEO Five Factor Inventory (1), a survey of the normal range of personality functioning. The NEO-FFI consists of 60 items presented in a Likert format (allowing participants to respond strongly agree, agree, neutral, disagree, strongly disagree).

NEO Personality Inventory (NEO-FFI) Domains:

Neuroticism (N) - Level of emotional stability
Extraversion (E)- Sociability, assertiveness, activity
Openness to Experience (O) - Imagination, aesthetic sensitivity, attentiveness to inner feelings, preference for variety, intellectual curiosity, and independence of judgment
Agreeableness (A) - Altruism, sympathetic to others and eagerness to help, belief that others will be sympathetic
Conscientiousness (C) - Self-control, determination

Mean and Standard Deviation NEO Five Factor Inventory T (Standard) Scores of Female and Male USAF Pilots

Domain	Women (n=48)	Men (n=64)	t value
Neuroticism	43.88 (7.94)	42.61 (8.40)	.81
Extraversion	62.44 (10.11)	58.06 (11.04)	2.15*
Openness	51.60 (9.88)	51.86 (11.00)	-.12
Agreeableness	54.29 (9.86)	47.44 (11.15)	3.38**
Conscientiousness	55.60 (10.06)	51.34 (9.52)	2.29*

Note: Combined sex norms were used in calculating T scores to facilitate gender comparisons.
*$p < .05$
**$p < .001$

This cross-sectional study looked at successful incumbent pilots, as opposed to the longitudinal Neuropsychiatrically Enhanced Flight Screening (N-EFS) program, which seeks to compare successful to unsuccessful aspiring student pilots (10) using the 240-item Revised NEO Personality Inventory. Another difference between N-EFS and APFA was that we also interviewed participants with a semi-structured interview. All APFA interviews were conducted by the second author (SEM), who is a female psychiatrist, to eliminate interviewer gender-bias effects.

MAB results of the APFA volunteers revealed no significant differences in intellectual skills, while a comparison of female versus male pilot personality structure suggests greater female extraversion, agreeableness, and conscientiousness. The observed lack of intellectual differences, despite the general population pattern of male versus female disparity (3), may be a function of selection (both self-selection and military personnel selection) and assignment. Conversely, these female pilots seem to have even more positive personality traits. Lyons (11) notes that all aviators have a unique psychological profile and female pilot candidates are not a representative sample of the general population. Hence, determination of *female* psychological fitness to fly is complicated.

While American Ace Brigadier General Chuck Yeager flatly asserts: "The ability to fly isn't determined by the shape of the reproductive organ" (Personal communication, 14 Feb 95), Jones (6) notes role conflicts when women are introduced into operational flying units. The first author (REK) served as the flight psychologist for the Euro-NATO Joint Jet Pilot Training (ENJJPT) during a time (1989-1990) when none of the approximately 330 student pilots per year were female, due to the fighter pilot orientation of the program (7). Even though some participating NATO countries allowed women to fly combat aircraft, the consensus was that it would be better for

there to be a critical mass of female student pilots rather than one or two ("token") female students.

On interview, the majority of male pilots voiced concern about their proclivity to protect women in combat. Female participants were concerned about potentially being used to exploit captive male comrades-in-arms, thus raising an important training issue. More women entered pilot training as a result of attending the United States Air Force Academy and finding that they were medically qualified, thus opening a career opportunity that they had not previously considered. Men typically offered that they entered pilot training as a culmination of a life-long desire to fly.

DISCUSSION

Educating women to potential career opportunities is a major selection issue illustrated by women attending the Air Force Academy and learning of aviation. New training needs, for both women and men, may arise as the number of a country's female aviators increase. These training needs appear to include helping men and women fight and endure captivity together.

Historically, the USAF has had the benefit of numbers sufficient for powerful statistical analysis, for both male and female pilots. This trend will likely hold for female fighter pilots. Opportunities for further study include directly comparing applicants and candidates for military flying training to incumbent pilots to address the aviation nature versus nurture argument. We need to discern whether pilot training *changes* women to be more like men or whether certain women self-select themselves into pilot training.

The USAF's experience with female pilots and mixed-gender flying squadrons may help guide NATO and Cooperation Partner Countries' air forces as their ranks of female aviators swell.

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THE ANALYSIS OF SAFETY INDICATORS IN THE AVIATORS' TRAINING

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SUMMARY

The prevention of aviation accidents used to be, in the former Czechoslovak Air Force in the centre of Commands attention. A system access to solving this problem area achieved the lowest losses of pilots and planes in the 1970s. Within the framework of validation of the methods, used in selection and training procedures, the analysis of the level in actual combat flight training was carried out in a fighter group (150 pilots) in the last years.

The achieved results confirmed the reliability of psychophysiological examination with cadets and the prognostic validity of the criteria used in the selection processes. With the 90% level of significance the hypothesis of personality predisposition to errors in flying by the individuals having a lower level of cognitive functions development and with the manifestation of the emotional irritability has been confirmed. The characteristics of test batteries and the relevant criteria used for the expertise together with account of incidents and accidents will be dealt with.

1. INTRODUCTION

Reliability testing and validation of selection methods in applied psychophysiology have become a general practice in most aviation medicine laboratories of all the developed armed forces. The Institute of Aviation Medicine in Prague has been using original Czech methods ever since World War II. In the 1970s these methods were adopted by a number of laboratories in the armed forces of the Warsaw Pact countries and also became a part of the operational methodology of the Soviet Union Air Force. The methodology was based on and further developed according to the theoretical analyses of professional pilot job descriptions conducted 1947-1960 by J. MLS and J. TUMA with the assistance of the Air Force school's flying instructors and the staff of the Institute of Aviation Medicine. In 1976 this methodology was used in selecting the group of the Czech cosmonauts.

The **battery of test procedures** is designed to assess the following:

1) **level of cognitive functions** (attention and short-term memory) using an optical and acoustic testing device under an induced time pressure;
2) qualitative level of **comprehension of picture contents and deductive capabilities** of the mind;
3) speed and precision in the **assessment of the optical and acoustic signal field** while registering motor responses (motion of limbs) and signs of emotion activation in the circulatory system.

Applicant's **personality** is assessed during a **structured interview** aimed at clarifying adequacy of the applicant's motivation complex towards flying, signs of emotional excitability and resistance to frustration and nervous distress. An integral part of the assessment is also **evaluation of objective data** concerning adaptation to the study load based on the students carried out by secondary schools teachers.

Resulting test scores are then transposed to a standard nine-point scale (stanine). The personality structure (development in adolescence) is evaluated using a fourpoint scale:

A - balanced, without neurotic symptoms;
B - general problems during adolescence resolved by personal power and emotional strength;
C - more pronounced signs of lability, unclear etiological pathogenesis, adjustment possible;
D - distinct psychopathic signs, low stress tolerance.

The results of psychophysiological examination integrate the test and clinical evaluation which are then summarized in the conclusion of the Medical Aviation Committee's assessment in four prognostic categories:

1.1 - fit for flying training without limitations;

1.2 - fit for flying training without limitations, with some reservations concerning laboratory performance but generally a good prognosis;

2.1 - fit for flying training with reservations as listed in diagnosis, development prognosis is uncertain;

2.2 - unfit for flying training, see the findings listed in diagnosis.

This concludes the **first** stage of cadet's selection. In the **second** stage the Acceptance Committee of the Air Force school conducts the usual tests of knowledge and physical fitness.
Prognostic ability of psychophysiological assessment in relation to the success in theory and in practice during the four year flying school course has been confirmed by

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a correlative analysis conducted between 1959 and 1962 and updated during the 1970s. The correlation coefficient, determined with the reliability level of 90%, is **0.74**.

2. PROBLEM

Following the introduction of supersonic aircraft in the general service during the 1960s, there has been a repeatedly occurring problem in developing a prognostication method to determine a success level in a combat training with the purpose of increasing effectiveness of flight hours and minimizing accidents of the expensive aircraft. Results of any studies, undoubtedly undertaken, were not, for obvious reasons, published in full.

At the initiative of the Air Force Commander of the Czechoslovak Army a multifactor study of a fighter combat group was conducted in 1988 (Kolouch, Wũnsche 1989), aimed at evaluating the professional reliability as well as assessing the further service prospects of the MiG 21 pilots. Prognostication strength of the above described selection methods, in relation to the study aims, was reaffirmed again.

3. METHODOLOGY

The study included 157 pilots of the age ranging from 27 to 40 years, with the number of flight hours ranging between 400 and 1500 hours, serving with the flying units for the past 10 years. The study was conducted by a five-member team consisting of:

1) Flight Safety Inspector of the Air Force Command;
2) MiG 21 Flight Inspector;
3) Deputy Commander of the Flying combat wing;
4) Social and Psychology Advisor;
5) Medical Officer/Psychophysiologist (the author of the study project and of this report).

Each pilot subjected to tests was evaluated according to the three-level scale (+1, [0], -1) in four categories of assessment:

A. **Motivation for continuing the flying service** (taking into account the frequency of medical problems and the general professional development).
   Attitude assessment categories:
   - clearly positive
   - uncertain, undifferentiated
   - negative

B. **Reliability in the flying training** (empirical evaluation of the level of flying skills by the inspectors, account of flight accidents, frequency of errors).
   Attitude assessment categories:
   - above average
   - average
   - below average

C. **Personal characteristics** (quality of interactions between the members of a squadron).
   Attitude assessment categories:
   - cooperating, initiative
   - rather passive, adjusting
   - dominating in disruptive behaviour within a group, symptoms of self-damaging activities

D. **Health condition of the pilot** (results of medical examination conducted by the medical aviation committee, frequency of health problems in the past 5 years).
   Assessment categories:
   - completely healthy
   - minor effects due to age changes, usual seasonal illnesses
   - adverse prognostic, frequent illnesses

The overall prognosis evaluation of prospective combat service used a point scale. There were nine points, from minus four to plus four.
Verbal evaluation levels were:
- **favourable prognosis**, points range: from plus two to plus four,
- **uncertain (indefinite) prognosis**, further evaluation required after a year of service, points range: plus one, zero, minus one,
- **unfavourable prognosis**, points range: minus four to minus two.

4. STUDY RESULTS

From 157 pilots (100%), monitored during the past 10 years, 6 died in flight accidents, 3 pilots successfully catapulted from the plane). 151 pilots provide a sample for assessment of relevant prognostic correlations.

Step 1

Correlation of the pilot's professional level with the frequency range of psychophysiological (PP) test results (PP prognosis "uncertain" - 2.1).

Pilots Evaluation

Professional Level	No. of Pilots	%
Above average	72	48
Average	59	27
Below average	20	15
Total	151	100

Frequency of PP Prognosis - 2.1

Professional Level	No. of Pilots	%
Above average (from 72)	14	19
Average (from 59)	27	48
Below average (from 20)	15	79

The work team assessed a group of 31 pilots (20%) as **"questionable"** due to difficulties in adapting to the flying training, in personal life and on the grounds of health condition. During the initial tests:

16 pilots of this group (50%) were classified under PP prognosis - 2.1 which was manifested during the combat training,

10 pilots were assessed as slow in acquisition of skills;
4 pilots had chronic health difficulties and
2 pilots had social/personal problems.

In the whole sample of **157** pilots (including the deceased ones) there were **59** pilots (37%) classified under PP prognosis - 2.1 with negative effects showing in 60% of those within 10 years of joining the combat unit.

Step 2
Incidence of pilot's errors during flight and occurrence of dangerous situations in relation to the frequency range of psychophysiological test results (PP prognosis "uncertain" - 2.1).

The group of 148 pilots (100%), without 6 deceased and 3 catapulted, was divided into two sub-groups.

Group D **"difficulties"** comprised 69 pilots (47%) with the record of one and more dangerous situations during flying, caused by themselves (i.e. mishaps).

Group C **"clear"** comprised 79 pilots (53%) without errors (mishaps) during previous flying training .

Frequency range of psychophysiological test results (PP prognosis uncertain - 2.1) within each group:

Group D
- 28 out of 69 pilots (40%) with the PP prognosis 1.1 + 1.2;
- 41 out of 69 pilots (60%) with the prognosis uncertain - 2.1.**)

Group C
- 66 out of 79 pilots (84%) with the PP prognosis 1.1 + 1.2;
- 13 out of 79 pilots (16%) with the prognosis uncertain - 2.1.**)

**) There was a significant statistical difference in the frequency range of psychophysiological test results.

Correctness of the prognosis "uncertain" - 2.1, has been confirmed by the significantly higher frequency in the group of pilots who had caused dangerous situations during flight (Group D).

These findings, concerning the frequency of the prognosis "uncertain" - 2.1, have confirmed the findings of ANASTAZI in relation to the conditions in our country.

Step 3

Incidence of accident and dangerous situations,

During 10 years (from January 1979 to December 1988) there were **512** dangerous situations (100%) recorded in the fighter plane combat group. Out of those there were **498** (97%) dangerous situations (incidents) that had been successfully resolved. There were **14** dangerous situations (3%) which developed unfavourably resulting eventually in accidents.

There were 5 dangerous situations (36%), **caused by an aircraft defect**, that were successfully resolved.

There were 9 dangerous situations (64%), **caused by the pilot's error**, that resulted in the death of 6 pilots and 3 pilots successfully catapulting from the plane.

There were 5 pilots (56%), initially classified under PP prognosis uncertain - 2.1, who have caused dangerous situation through their own error. Three out of the 6 pilots who died (i.e. 50%) were classified under the prognosis uncertain - 2.1.

5. DISCUSSION

It is not possible to make further quantitatively oriented comment concerning the results obtained in the above presented 10-year long study of the fighter combat group concerning the number of accidents and dangerous situations. The reason is simple, the combat group was dissolved .

In statistical terms the number of accidents was relatively small hence we cannot expect a high level of probability that the deductive statements made will be generally valid.

For the long-term preventive practice of psychophysiological medicine there have been collected exceptionally valuable findings which provide statistical evidence for the significant coincidence in the incidence of personality variables predisposing a greater probability of an individual to make an error during flight. Personal dispositions may be described in terms of methodology and, insofar as the general signs are concerned, considered as foreseeable to some degree of probability.

To the commanders, this study of the select range of factors describing the level of fighter pilots combat training, provided means for a more objective evaluation of individual qualities and helped some of the individuals themselves in deciding that it would be better to choose a more suitable career.

A recognized deficiency of the study is that the analytical assessments cannot be repeated which prevents therefore to restate the uncertain predictions with a greater degree of precision. We have also avoided making correlations with the number of flight hours, due to the reasons of economy. General estimate, in the case of the "questionable" group of pilots, confirmed the generally accepted fact that the greatest number of errors and

accidents occurs in the group of pilots with 500-600 flight hours and then among the individuals with an exceedingly high level of self-estimation.

The study made in 1988 also included a paragraph describing in detail the probable versions of causal chains in the accidents that occurred and, also, the resulting preventive measures. We dealt to a great detail with the interaction of external and internal factors contributing to the occurrence and resolution of these events. These factors were classified and stored in the computer database.

As to the methodology that allowed us to grasp the problem with a greater degree of precision, it would be recommended to use the five-point assessment scale at present instead of the threepoint scale chosen at the time because it seemingly simplified the process of decision making. The five-point scale, however, describes the "fuzzy" character of the monitored events better. Updated procedures may then be used in selection of pilots of the new generation planes.

6. CONCLUSIONS

1. Towards the end of the 1970s the methodology used in the psychophysiological laboratory of the Institute of Aviation Medicine allowed to predict difficulties in the combat training for 50 - 60% of pilots. Continuous comparison of the results with the practical findings collected during flying training will assist the commanders to make decisions in devising a personalized approach to the flying training. From this point of view, the furthering of development of new methods in this area is desirable.

2. Assessment of professional effectiveness of the military air force pilots contributes further to the improvement of the result processing within a team allowing directly to compare and explain varying views and enabling to reach conclusion.

3. At present the problems concerning the Czech military air force are dominated by the problems of logistics while the prospective solutions are not viewed with great optimism.

THE CANADIAN AUTOMATED PILOT SELECTION SYSTEM (CAPSS): VALIDATION AND CROSS VALIDATION RESULTS

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1. The current pilot selection system used by the Canadian Forces to assess pilot applicants incorporates paper and pencil ability tests ,and an evaluation of psychomotor skill measured on a general aviation trainer. Each measure is weighted differently and the scores are then combined together to give candidates a final Pilot Stanine (PS). Although able to satisfactorily select candidates for pilot training, the increasing complexity of modern aircraft and the high costs associated with training have led the CF to adopt a new selection measure, the Canadian Automated Pilot Selection System (CAPSS) which will be implemented in January 1997.

2. CAPSS is a stand alone selection device which provides a measure of complex cognitive abilities and psychomotor coordination. The underlying constructs which CAPSS is measuring are:

a) psychomotor coordination;

b) learning rate;

c) multi-task integration; and,

d) performance under overload.

3. CAPSS uses flight simulation technology and is comprised of two main elements - a simulator test facility and an analysis center. The simulator test facility consists of a Singer-Link general aviation trainer, audio visual devices for providing instruction and performance feedback and interface equipment and software programs for implementing the training syllabus and for recording performance data. The interior of CAPSS accurately portrays a single-engine light aircraft.

4. CAPSS operates by both demonstrating and collecting performance data on a sample of the flight skills needed to fly a single engine light aircraft using Instrument Flying Rules (IFR). Candidates proceed through a syllabus consisting of five one-hour sessions which take the applicant from the initial position of knowing nothing about the operation of the aircraft or simulator to the point where, by the end of the fifth session, they can make climbing, descending and standard rate turns and execute airport traffic patterns. In each segment, or task, the candidate is presented with detailed and step-by-step instructions in the operation of the CAPSS simulator and is provided with one or more practice sequences. CAPSS manoeuvres were selected and sequenced so that each segment is an extension of, and uses the skills learned, in the previous session. Table one outlines the tasks taught in each one hour session.

Table 1

CAPSS Syllabus

Session	Tasks
1	Basic flight instruments and controls; straight and level flight; climbing; descending.
2	Review; take-off, climbout and level-off procedures; level turns; standard rate turns.
3	Review; climbing turns; descending turns.
4	Review; rectangular course; airport traffic pattern.
5	Review; traffic pattern with side tasks, landing procedure.

An Overview of Canadian Forces Flying Training

5. Candidates enrolled in the CF as pilots first undergo Primary Flying Training (PFT) which consists of approximately 17 hours on the CT-67C Slingsby aircraft. If successful they proceed to Basic Flying Training (BFT) which consists of approximately 95 hours of training on the CT-114 Tutor jet aircraft. Successful candidates are then assigned to one of three streams; jet aircraft, multi-engine aircraft or rotary wing aircraft. If assigned to jet aircraft, candidates receive a further 87 hours of training on the Tutor. If assigned to multi-engine aircraft they undertake a further 70 hours of training on the CT-145 King Air aircraft. Candidates assigned to rotary wing aircraft then complete Basic Helicopter Training which consists of 90 hours on the CH-139 Jet Ranger.

A Summary of CAPSS Prediction Research

Data Collection

6. As a candidate operates CAPSS, data is recorded at the rate of twice per second on eight flight parameters; engine speed, bank angle, heading, airspeed, turn rate, side slip, altitude and vertical speed. By the end of the fifth hour of CAPSS operation each candidate has accumulated between 150,000 to 200,00 raw data points. This data is then categorized according to the type of manoeuvre the candidate was performing at the time the data was recorded. For instance, was it a straight and level flight or a climbing turn? What was the context in which the task was performed? Was it a practice manoeuvre or part of a complex flight task? What was the repetition number of the task performed? What flight parameter, or instrument, was being monitored and was the data extracted at the beginning or the end of the flight task?

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7. This categorizing of the data results in the creation of 880 data sets, per candidate, which are then collapsed into manageable summary measures which are designed to assess the candidate's performance on the following:

a) the candidate's accuracy in keeping flight instruments at the ideal parameter;

b) the candidate's variability in performance;

c) the candidate's speed of response to errors and warnings;

d) the candidate's smoothness of operation and avoidance of over-corrections;

e) the candidate's coordination of the flight controls; and,

f) the number of instances and amount of time the candidate spent flying towards or away from the ideal flight parameters.

It is these summary measures which represent the candidate's proficiency in operating the simulator.

7. In order to develop the scoring program for CAPSS, statistical analyses related these summary measures to actual flying training outcomes and a prediction equation was developed for each hour of CAPSS operation. Each equation yields a CAPSS score, for any given candidate, which is the probability of the candidate passing flying training based on that particular hour of CAPSS operation, in addition to any hours which preceded it. For example, a candidate's CAPSS score for hour four is the probability of a candidate passing flying training based on the information obtained from hours one through four of the CAPSS sessions. The scoring range is from 0 to 1. Thus a candidate who receives an hour four CAPSS score of .75 has a 75% chance of passing flying training.

8. The first predictive study carried out on CAPSS focused on candidates' success at PFT and used a sample of 225 male Anglophones. It was found that CAPSS was able to successfully predict the outcome of Primary Flying Training for 201 - or 89% of these candidates. However, it was known that the use of stepwise procedures for equation derivation resulted in inflated figures and a cross-validation study was needed in order to achieve a more accurate estimation of the predictive ability of CAPSS.

9. The cross-validation of CAPSS' predictive ability at PFT was carried out using a sample of 172 male Anglophones and it was found that CAPSS retained its ability to significantly outperform the current selection system. 75% of candidates were correctly classified and 79% of those predicted to pass did so. Further, the loss rate, or the number of candidates who are not selected for training but who would pass if selected, was estimated at 57% for the current system but at less than 20% for CAPSS.

10. But the most important test for CAPSS was to determine if it could predict success to Wings Standard, or the completion of flying training. A sample of 309 male Anglophone candidates was used to determine the ability of CAPSS to predict success at BFT. Analyses indicated that CAPSS was able to correctly predict 82% of candidate results. The loss rate was 8.2%. CAPSS clearly outperformed the current selection system. However, as with the initial figures for PFT, it was again known that the use of stepwise procedures for equation derivation resulted in inflated figures and that a cross-validation study was necessary.

11. The cross-validation was performed in 1995 on a sample of 110 candidates and it was found that CAPSS was able to accurately predict 69% of candidates' overall performance. The loss rate was 20.9%. However, it should be noted that the decline in CAPSS' ability to predict candidates' performance was significantly affected by an unusually high pass rate for this sample - fully 80% of candidates passed training, compared to the historical pass rate of between 55-60%. However, notwithstanding this difference in the samples, CAPSS was still able to accurately predict 85.5% of those candidates who passed training - of the 78 candidates who CAPSS predicted would pass training, 66 actually did so. Most importantly, despite the decline in the predictive ability of CAPSS, it maintained it's ability to outperform the current selection system. Table 2 details the results of validation analyses performed.

Table 2

Percentage of Candidates Correctly Classified by CAPSS

Study	N	% Correctly Classified
Initial Validation - PFT	225	89%
Cross Validation - PFT	172	75%
Initial Validation - BFT	309	82%
Cross Validation - BFT	110	69%

12. It should be noted that CAPSS' best correlation with flying training outcomes consistently occurred at hour four. The correlation coefficient was .32 in the BFT cross-validation and it is the hour four results which will be used to select candidates when CAPSS is implemented. Experimentation with the hour five syllabus will, however, continue.

13. As stated, the Canadian Forces will implement CAPSS in January 1997. Utility analyses indicate that the use of CAPSS will save the CF approximately 4 million dollars for every 100 pilots which are graduated. The total cost of development and implementation, estimated at approximately 4-7 million dollars Canadian, will be recouped in three years.

ANALYSIS OF PSYCHOMOTOR PERFORMANCE OF FIGHTER PILOTS DURING FLIGHT

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SUMMARY

Eighteen healthy males with different degrees of flight experience were tested during piloting an L-29 jet-trainer plane during 54 standardized aerobatic flights. In 13 pilots up to four successive aerobatic flights were realized, separated by half an hour intervals on the ground.
The ranks of the expert evaluated in-flight psychomotor performances during standardized aerobatic flights and of the values of the individual total flight time hours were highly significantly correlated ($r = 0.86$).
Computer based analysis of the quality of performance of flight manoeuvers showed that the pattern of piloting the plane was highly individual. Nevertheless, the coefficient of reliability of the courses of repeated flights of experienced pilots (normalized as to the duration of each manoeuvre and the maximal G-level reached) equaled to $r = 0.97$. Evidently, the individual pattern of flying is a stable characteristics of the performance of experienced pilots. It is something like their signature.
Results of analysis were compared with other indices of pilot's performance under the influence of hypergravity.

1. INTRODUCTION

The purpose of present study was to increase the objectivity of the evaluation of actual performance of pilot during the flight.

In terms of our interdisciplinary bio-psycho-social (BIOPSYS) approach following criteria were chosen:

(1) total flight time,
(2) psychomotor performance in piloting the plane during a standardized aerobatic flight, as a parameter of pilot training,
(3) heart rate reactions to accelerations during standardized aerobatics, as a parameter of actual situation oriented somatic reactivity,
(4) results of psychological testing before and after the flight, as a parameter of psychophysiological state.

2. METHODS

Eighteen healthy males with different degrees of flight experience (6 test-pilots, 11 pilots from a regular jet-fighter squadron, 1 experienced pilot resuming duty after 20 years of grounding), aged 27 - 55 years (mean 42.0 years), having 400 - 4000 flight time hours (mean 1886 hours), were tested during piloting an L-29 twin jet-fighter trainer plane during 54 standardized aerobatic flights. In 13 pilots during each exposition up to four successive aerobatic flights were realized, separated by half an hour intervals on the ground.

Heart rate and +Gz acceleration force were registered continuously by a portable apparatus BIOPORT (ZAK). The mood adjective checklist was administered prior and after the flight to record the mood state. Critical flicker fusion frequency was tested prior and after the flight to determine fusion threshold.

The curves of accelerations during each standardized aerobatic flight as a whole were qualitatively analyzed by expert judgement. Moreover computer based evaluation of in-flight performances of six pilots from the group was realized. The flight evaluated as the best was taken as the norm. Each flight was separated into four phases and compared with the norm. The curves were normalized as to the duration of each manoeuvre and the maximal G-level reached. Covariances and coefficients of correlation were computed (1).

Schematic representation of the standardized aerobatic flight is in Fig. 1. The pilots were instructed to perform following manoeuvres: left and right turns, backing, looping, distortion, and roll.

3. RESULTS

All subjects tolerated repeated expositions very well. No symptoms such as grey- or black-out and/or fainting were observed.

No significant changes were determined in mood state, and in fusion threshold respectively. Accordingly, no

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differences in these psychological parameters were found in relation to the time or number of flight.

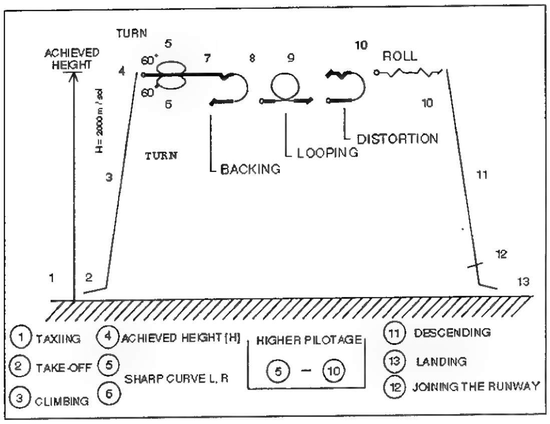

Fig. 1. Flight scenario

Two examples of the courses of real flight trajectories in pilots with different degrees of experience are presented in figures 2 and 3.

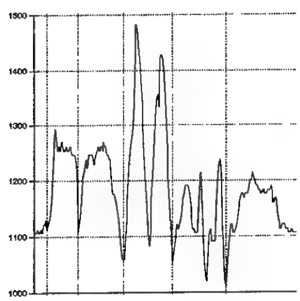

Fig. 2 The curve serving as a pattern. The flight was devided into four phases (left turn - right turn - looping+distortion - roll).

Regular pattern of piloting the manoeuvre, presented in Fig. 2, is from an experienced pilot (4000 total flight time hours). This curve was taken as an ideal representation.

Much less regularity was observed in less experienced pilot (2200 total flight time hours) in Fig. 3.

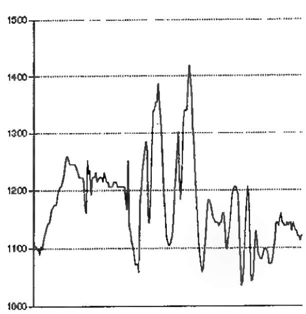

Fig. 3

Initially, the values of the individual total flight time hours of all subjects were put into the sequence in ascending order.
The ranks of the expert evaluated in-flight psychomotor performances during the mentioned standardized aerobatic flight as a whole were highly significantly correlated with the ranks of individual total flight time hours ($r = 0.86$).

Subsequently, each flight was divided into four phases in accordance with the manoeuvre performed. Covariances and correlations with pattern curve for each phase were computed.

The evaluation of acceleration curves showed promising results. Correlation coefficients of assessed curve with pattern curve varied for the four given phases as follows:

Phase 1 (left turn)	0.89 to 0.70
Phase 2 (right turn)	0.88 to -.19
Phase 3 (looping+distortion)	0.87 to 0.57
Phase 4 (roll)	0.48 to -.14

The reason of apparently lower correlations of acceleration curves when performing the roll appears to be due to the possibility to perform this manoeuvre by different ways.

The correlation of covariances with the expert evaluated rank of psychomotor performance for the whole aerobatic flight varied between $r = 0.83$ for the Phase 1 of flight (left turn) to as low as $r = -0.03$ for the Phase 4 (roll); these were higher with the rank of the total flight time hours, varying between $r = 0.84$ for the Phase 1 to $r = 0.27$ for the Phase 4.

4. CONCLUSIONS

The aim of our research was to increase the objectivity of the evaluation of the quality of fighter pilots psychomotor performance. As yet their performances were interpreted subjectively by ratings of flight instructors, participating in flight.
When surveying the literature dealing with topic addressed we did not find results of an objective evaluation of pilots' in-flight psychomotor performances in relation to their flight experiences. Nevertheless it can be seen from classical papers (5, 6) that such manifestations exist.

Computer based analysis of the quality of performance of flight manoeuvers showed that the pattern of piloting the plane is highly individual. As old pilot instructors use to say, "there are as many turns as there are pilots". Pilots' performances were not identical in different phases of the mentioned standardized aerobatic flight; this is probably related to the difficulty of flying the manoeuvre or to the higher possibility of individual interpretation of the pattern of flight manoeuvre.

At the same time, if the courses of repeated flights of each pilot are compared, the differences appearing without doubt as a result of adaptive processes, are marked, but as a whole negligible. Evidently, the

individual pattern of flying is a stable characteristics of pilots performance, the coefficient of reliability being equal to r = 0.97.

Computerized analysis of the in-flight acceleration changes seems suitable for evaluation of the individual quality of flying of pilots, members of aerobatic groups, or of the assessment of the gradual increase of in-flight performance in pilot - candidates.

All changes were related to the pilots' total flight time hours, i.e. to their flight experiences, not to their ages (see Table 1).

Table 1. Spearman correlation coefficients (N = 13)

TFT - total flight time hours
FP - in-flight performance
HRF - heart rate fluctuations
A - age (years)

	TFT	FP	HRF	A
TFT				
FP	.86			
HRF	.92	.96		
A	.76	.51	.63	

Evidently, it is possible to formulate objective indices of pilots' in-flight performances more simply on the basis of the qualitative changes of the +Gz component of accelerations during standardized aerobatic manoeuvers, based on expert evaluation. Such changes are closely correlated with differences in heart rate fluctuations during hypergravity. The correlation of the ranks of the expert evaluated in-flight psychomotor performances and of those of the heart rate fluctuations was highly significant (r = 0.96). These results are to be published elsewhere.

In experienced pilots the better psychomotor performance was registered together with circulatory adaptation to hypergravity. This is without doubt a sign of adaptive adjustment supporting recent findings of right heart hypertrophy in fighter pilots, as published by our French colleagues (2, 3, 4).

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Current Status and Future Developments of RAF Aircrew Selection

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SUMMARY

This paper summarises the current status of the RAF aircrew aptitude selection process against work conducted during the previous decade and identifies a number of problems and possible future directions. An ability domain structure was explored and incorporated into the current test development policy. This concept was further expanded to develop a validation model which uses wider and more detailed criteria to provide a more accurate and informative estimate of selection measure validity.

LIST OF SYMBOLS

r validity correlation coefficient

1. INTRODUCTION

The selection of all Royal Air Force (RAF) aircrew takes place at the Officers and Aircrew Selection centre (OASC) at RAF Cranwell. Historically, different categories of candidate information have been used for selection: aptitude for specific roles, personality/character traits and biographical information for overall officer suitability.

Aptitude tests have been the most extensively researched of all selection measures. Currently, the tests are organised into batteries designed to select for specific roles. The four main batteries are those for pilot, navigator, air traffic controller and fighter controller. Each battery produces a composite aptitude score for selection.

The current Pilot Aptitude score is the simple summation of scores from five executive tests which are collectively called the Pilot Aptitude Test Battery. These tests together with the specific ability measured (in square paratheses) are: Control Velocity Test (CVT) [*an anticipatory tracking task which involves eye-hand co-ordination*], Sensory Motor Apparatus (SMA) [*a compensatory tracking task which involves eye-hand-foot coordination*], Instrument Comprehension (INSB) [*a test which involves an interpretation of aircraft instrument dials, reasoning and mental speed*], Vigilance [*a monitoring task which involves visual attention*], and Digit Recall [*a short term memory test*].

Past validation studies have indicated that the Pilot Aptitude Test Battery is a good predictor of early flying training success (ref 1 & 2). The predictive validity of the test battery was shown to be 0.52 (after correction) in the latest validation study (ref 1).

2. APTITUDE TEST DEVELOPMENT

Aptitude test development is normally a three stage process comprising job analysis, test construction and test validation. The job analysis identifies required job aptitudes and provides a framework for directing test development. However, this can be a time consuming and costly exercise. In the absence of a job analysis, test design has tended to be driven by psychometric theory and the availability of adequate test delivery systems. Traditionally, as a compromise, new tests which are thought to have the potential to predict training success are usually designed on an *ad hoc* basis and then validated when there is sufficient data to provide a reliable estimate of their validity. Tests with adequate predictive validity are then incorporated into the test battery for selection.

However, this validity driven approach does not impose structure on test batteries which are constructed without a predefined framework. Secondly, there is the question of choice of criterion for validation. As a result, this RAF traditional approach to test development was reviewed and these two issues are discussed in this paper.

3. TEST BATTERY STRUCTURE

Pitfalls of Traditional Validity Driven Approach

The structure of a test battery is often dependent upon the results of any particular validation study. Valid tests are included and non-valid tests excluded irrespective of the final composition of the battery. Consequently, the battery structure may be biased by the quality of particular tests subjected to the analyses in that only good tests will contribute to the structure. For example, spatial ability may have been relevant but the test used to operationalise it may have been psychometrically poor and consequently rejected as a useful selection measure. Also, the battery structure may be biased by the range of tests subjected to the analysis. For example, mental speed may be relevant but no tests of it may have been available to be included in the validation study.

Furthermore, subsequent validation and cross-validation studies may also change the composition of the battery. The actual weight attached to any particular test in the battery is determined by the statistical weight assigned to it from, for example, the regression analyses employed during the test

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Domain	Description
Reasoning (R)	Relates broadly to general problem solving capability or which is sometimes referred to as general or effective intelligence.
Mental Speed (MS)	The ability to perform simple tasks quickly and accurately often under the pressure of time
Spatial Ability (SA)	The ability to form and manipulate mental shapes and patterns in the 'mind's eye'.
Attentional Capability (AC)	Refers to the effectiveness and efficiency with which an individual can deal in real time, with visual and auditory stimuli (information) from the environment.
Psychomotor (P)	Eye-hand or foot-eye coordination skills.

Table 1: Current set of ability domains adopted by OASC

validation process. These weights are generated to explain maximum possible amount of variance in the data set and are driven by a given data set. However, validation studies are not always based on high quality data sets and regression generated test weights may not be replicated in a second (cross-)validation. These effects of repeated validation studies on test battery structure are subtle and, over time, may dramatically distort the nature of the battery.

Bradshaw (ref 3) describes some of these pitfalls more fully and concludes that "some structure should be defined and imposed upon a test battery otherwise the structure is a *hostage to fortune* and dependent upon the design and outcome of successive validation studies" (ref 3, p5).

Domain Centred Approach

One approach to impose structure is to use the *domain centred approach* to dictate the structure and content of aircrew test batteries and to focus future aptitude test research and selection policy. This alternative approach was originally, and informally, introduced by Burke in the early 1990s and later developed by Bradshaw and Hobson. It moves the emphasis in selecting aptitude tests from the actual tests which constitute a battery to the aptitude domain which the tests measure. An ability domain is a broad collection of a number of similar aptitudes and thus provides a more robust approach to aptitude testing.

In practice, any number of domains may be defined and the working set of domains will probably evolve over time dependent upon organisational requirements. Table 1 shows the current working set of domains adopted by the OASC. These five domains are not the product of a formal exploration of this issue and the domain taxonomy may require modification. For example, the rather broad attentional capability domain may be reasonably fractionated and replaced by attentional flexibility and memory capacity domains.

The introduction of the domain driven approach forces a re-consideration of current RAF test batteries and the assignment of specific tests to one or more of these domains (ref 3, 4 and 5). However, this is not easy because there is not always a good one-to-one correspondence between tests and domain.

Consistent with the domain driven approach, Hobson (ref 6) produces the following specific model for the pilot aptitude test battery - *equation 1.* Note that a percentage weight is applied to each domain marking the importance of that particular domain which can be accounted for by the test battery.

$$\textit{Pilot Test Battery}_{current} = 10\%\,R + 10\%\,MS + 0\%\,SA + 40\%\,AC + 40\%\,P \qquad \textit{Equation 1}$$

This current pilot test model was driven empirically and has been shown to be valid (r=0.52 [ref 1]). However, because this model does not use all five domains then there is a possibility that the battery is not optimised for pilot selection. Therefore, there is a need to determine whether all five domains should be incorporated into the Pilot Aptitude test model and what weight should be assigned to each domain. In other words, there is a need to define the structure for an ideal Pilot Test Battery.

Rational Weight Approach to Task Analysis

A rational weight approach was used to define the structure. It may be considered equivalent to a broad, very basic and undetailed job analysis. It uses subject matter experts to assess the relative importance of aptitude domains for different roles.

Subjects matter experts are those individuals who are deemed to have a thorough knowledge of the work role under consideration. Each subject matter expert is asked to evaluate the ability domains and suitability of available tests, by assigning a percentage weight to each ability domain to reflect its relative importance, and by rating each test on a five point scale, to indicate its perceived value for selection.

The first rational weight study was introduced by Bradshaw (ref 3) for navigators. Results of the latest pilot rational weight study (ref 6) generate three specific rational models of

the pilot test battery; one for the Fast Jet, one for the Multiple Engine and one for the Rotary Wing. However, statistical analysis (MANOVA) shows that there are no significant differences between weights of the three models. So, a combined model was chosen for selection. Further statistical analyses demonstrated that the model could be simplified because there are only small differences between percentage weights assigned to each domain. It was concluded that an equal weights model should be adopted. The combined model (Pilot Test Model$_{rational}$) described below (*equation 2)* is the best representation of the data to be used to select all pilot candidates, regardless of the pilot role they might assume in basic flying training.

$$\textit{Pilot Test Model}_{rational} = 20\% R + 20\% MS + 20\% SA + 20\% AC + 20\% P \qquad \textit{Equation 2}$$

Two points arise when this proposed rational model (equation 2) is compared with the current empirical/validity driven model (equation 1). First, the current RAF validity driven model gives a much lower weighting to the mental speed and reasoning domains than the proposed rational model. Secondly, the spatial ability domain is given a zero weighting in the validity driven model whereas it *is* given a weighting in the rational model.

This suggests that changes to the current pilot test battery would prove beneficial. In any process, an additional functional job analysis, based on the rational weight approach, should ideally be carried out to provide specific details of abilities required for each specific task. Such an analysis will augment the broad rational weight analysis.

In the fighter controller functional job analysis (ref 5), for example, all major job functions were grouped and broken down into operational units in the form of a hierarchical chart. The subject matter experts then rated each unit for its importance, complexity and frequency. They also re-evaluated the five individual ability domains for each unit. There are two end products to such a functional job analysis. First is a test model consistent with the rational approach and related to actual job tasks. Second is a competency model with content details of the types of test required for candidate selection. The fighter controller functional job analysis, for example, identified that 25% of the aptitude test battery emphasis should be related to the mental speed domain and that mental speed tests should reflect both speed of thinking/making decisions and speed of executing decided actions (ref 5). Functional task analysis provides useful details for the development of tests.

4. CHOICE OF CRITERION

In common with those of other organisations, the RAF selection tests are designed to give some indication of how well a candidate will perform in the job selected. The validation of selection tests is the method of determining the effectiveness of a selection measure - how well it will select the right candidates for the job.

Pilot aptitude tests are designed to select candidates who perform well during flying training. Traditionally, the Basic Flying Training element of RAF flying training has been used as the 'yardstick' or criterion by which the effectiveness of pilot aptitude tests have been measured (ref 2). The pilot training pattern is a lengthy process and is periodically under review. For the purposes of this paper, two highly simplified descriptions of pilot training are presented in figures 1 & 2 (on this and the next page) representing the pre- and post-April 1995 flying training systems. The most significant change is the move of role streaming from post-Basic Flying Training to post-joint Elementary Flying Training. In other words, streaming for role specialisation is being made earlier. This raises the issue of whether candidates can be identified for different specific flying roles at the initial selection stage at OASC using aptitude tests.

Accuracy of Information Provided

As the purpose of validation is to provide an accurate indication of the effectiveness of a selection measure, the choice of criterion against which the measure is assessed is

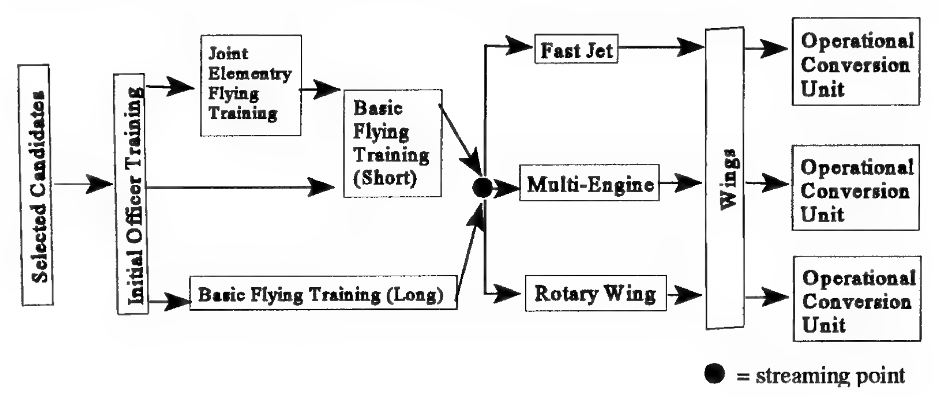

Figure 1 *Pilot Training Pattern - pre April 1995*

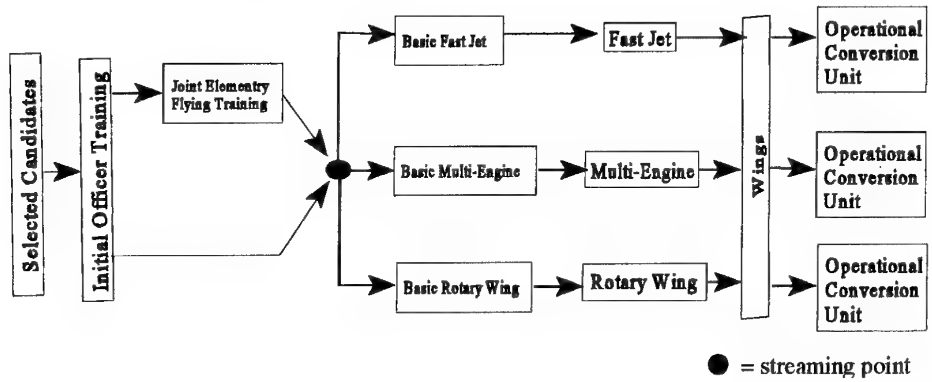

Figure 2 *Pilot Training Pattern - post April 1995*

crucial. There must be a strong theoretical relationship between the selection measure and the criterion used. For example, if it is the aim of the selection measure to predict successful instrument flying at a particular stage of flying training, then the criterion used must to some degree reflect student pilots' ability to fly using instruments. Ideally, the more specific the selection test, the more specific the criterion should be.

Often only more global criteria are available. Traditionally, pass or fail at Basic Flying Training was used as the criterion for pilot tests validation. This is a broad global criterion as it encompasses a number of minor local assessments of student pilots' performance on areas such as instrument flying and navigation. In the Bradshaw and Hobson study (ref 2), all five pilot aptitude tests were validated against this pass/fail criterion and the tests were deemed valid (r=0.49 after correction [ref 2]).

The use of pass/fail criterion has some advantages. If it is assumed that the Pilot Aptitude Test Battery is designed to predict overall performance in Basic Flying Training, then an overall index of success at Basic Flying Training is appropriate because its breadth should encompass most of the core skills required in training. Furthermore, it is a central part of the RAF pilot training pattern and thus an immediately tangible criterion against which selection measures can be validated. (-see fig. 1 & 2). It is also a relatively constant criterion and this will permit the effectiveness of one test to be directly compared with effectiveness of another.

However, the nonspecific nature of pass/fail criterion may attenuate some of the tests' true validity coefficients because the whole of the criterion will not relate to the individual tests. If a criterion is too broad, unwanted information may be present. The pass or fail outcome does not provide information about which parts of the training course the student performed well or less well. All it shows is whether the student passed or failed *overall* at Basic Flying Training.

The Use of Continuous vs Dichotomous Criteria

The amount of information contained within the criterion also has important implications for studies which employ correction techniques for range restriction or dichotomisation of the criterion. Criterion data may be on a continuous scale (e.g. a rating from one to nine) or dichotomous (e.g. pass or fail). As discussed above, the traditional criterion used in RAF pilot validation studies is pass/fail. Because it is dichotomous, it does not provide information about how well or less well the student is performing overall or in any specific areas. It is simply pass or fail at Basic Flying Training with nothing in between. However, continuous data is preferable because it usually contains more information on individual performance than dichotomous data.

Furthermore, dichotomous criteria place an upper limit on the maximum theoretical correlation coefficient that can be obtained from a validation study. The effect is most significant when the dichotomy (e.g. pass rate) deviates significantly from 50%. Such a deviation will attenuate the coefficient and statistical procedures are usually applied to correct for the dichotomy. Nonetheless, when the deviation is high the criterion contains less information concerning individual performances and is less useful for estimating validity coefficients.

In the Bradshaw and Hobson study (ref 2) a high proportion of the sample (87%) fell one side of the dichotomy (the 'pass' side). They addressed this imbalance by treating those students who recoursed in training as failures. This changed the criterion to ***pass first time vs. pass on recourse or fail at Basic Flying Training*** and reduced the pass rate to 70%. They also corrected the correlation coefficient to 0.49 (ref 2) for the effect of dichotomisation.

If the pass rate continues to increase at Basic Flying Training the usefulness of the pass/fail criterion will decrease in proportion. Therefore, despite the availability of correction procedures, criterion data should ideally be on a continuous scale to obviate the need for any statistical correction for dichotomisation.

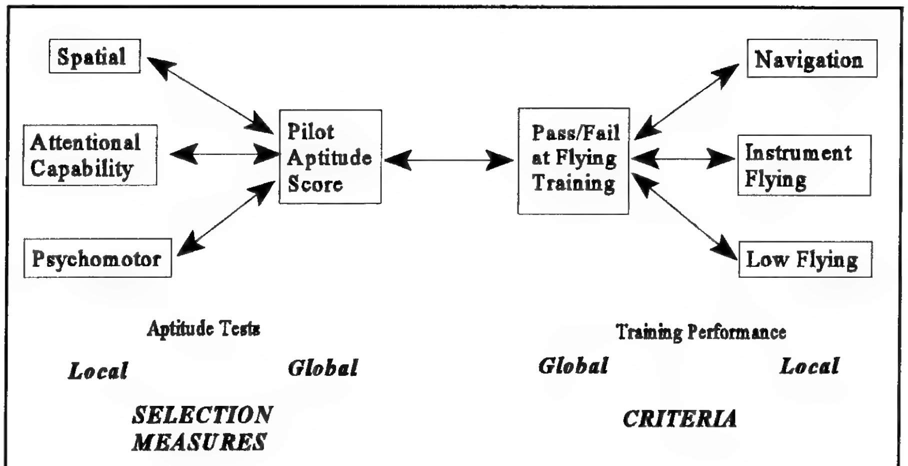

Figure 3 *Validation Model (illustrated example)*

5. CURRENT VALIDATION MODEL

The domain centred approach to test battery construction, and the criterion issues discussed so far, aid the formulation of a simple validation model which is now applied to all RAF validity studies as part of the test development programme. The concept was first introduced by Bailey (ref 7) to validate officer qualities assessment scores and the model was further developed by Hobson (ref 1 and 8) for pilot validation.

This model may be best illustrated using the following example. If a job analysis revealed that a spatial ability test might be a useful selection measure for the navigator part of flying training, it would be incorporated into the battery which would then give rise to a composite Pilot Aptitude score, which might comprise other measures of attentional capability and psychomotor. Although the new spatial test would relate in part to the overall pass/fail result in flying training, it might relate best to the specific part of flying training concerned with navigation. Thus validation against this criterion would provide the best estimate of that test's performance. Also, in this way, that test's performance would not be overshadowed by other tests within the same battery.

The model basically makes the distinction between local and global selection measures and local and global criterion measures. Figure 3 above further illustrates this validation model by showing it as a diagram using the same example. The left of the diagram presents the tests as the *local selection measures* all relating to the composite Pilot Aptitude score which is the *single global selection measure.* The right of the diagram presents student pilots' performance in three different flying training fields as *local criteria* and the overall pass/fail result at the end of training as the *global criterion.*

This model provided the framework for Hobson's latest 1995 pilot aptitude tests validation study (ref 1). He validated the five aptitude tests in the current Pilot Test Battery against a number of criteria collected at the RAF Basic Flying Training to give a more detailed insight into the performance of the aptitude tests. The ten flying training areas of most interest to aptitude testing are: Aerobatics, Captaincy & Airmanship (Captaincy), Performance Under High Workload (Capacity), Formation Flying, General Handling, Instrument Flying, Low Flying, Navigation, Night Flying and Academic Knowledge Final Grade (Ground School Result). Students are graded on each of these training areas using a one to seven scale (labelled 'below average' to 'exceptional'), except for the Ground School Result which is given as a percentage. In addition, Hobson (ref 9) added the nine flying assessment scores (ie. all criteria except the Ground School Result) to

Overall Flying Result		
TEST	**validity coefficient (uncorrected)**	**validity coefficient (corrected)**
CVT	.15	.20
SMA	.17	.20
INSB	.08	.12
Digit Recall	.19	.21
Vigilance	.25	.31
Pilot Aptitude	.30	.52

Table 2 Test Validity coefficients (Overall Flying Result Criterion)

give a tenth result - 'Overall Flying Result'. This was simply a hypothetical summary score which was used to determine the overall effectiveness of the tests across all nine flying training criteria.

Table 2 on the previous page presents correlations between the Overall Flying Result and each of the selection variables. Correlations of the individual tests with Overall Flying Result range from 0.12 (moderate) for INSB to 0.31 (good) for Vigilance. The overall coefficient for the Pilot Aptitude battery is 0.52 after correction for range restriction (high).

Table 3 below gives further insight into the different aspects of flying training that each test predicts. It presents correlations between the Pilot Aptitude score and each of the flying assessments. It is worth noting that the two psychomotor tests (CVT and SMA) predict reasonably well for Aerobatics, Formation Flying and General Handling and that two tests, which also form part of the RAF Navigator test battery (Digit Recall and Vigilance), both predict well for Navigation. Moreover, both Digit Recall and Vigilance predict well for Capacity, Captaincy and Airmanship, all of which are commonly cited in supervisor reports as areas of failure. Finally, Vigilance appears to predict well for all nine assessments providing further evidence that it is one of the most predictive executive selection tests.

In practice there is the potential for all variables to inter-correlate. However, the potential benefits of this validation model outweigh its potential problems. For instance, a more accurate assessment of a test's true validity can be made because this model refers to a more specific relationship between tests and training performance. Specific tests which show poor validity when validated against a global criterion may show high validity when validated against the appropriate local criterion. Thus, tests which are useful selection measures will not be discarded because their true validity is hidden when validated against a global criterion. Moreover, the observed validity is less likely to be suppressed by a dichotomous criterion because most RAF training performance scores are on a continuous scale.

6. EXPANSION OF THE MODEL: MULTI-CRITERIA VALIDATION

The model discussed so far may be used at any specific validation point in training (e.g. end of Basic Flying Training) or it may be expanded to include more than one validation point (e.g. end of Basic Flying Training and end of Advanced Flying Training). Comparable criterion data can be made available from almost all courses in the RAF Flying Training system. Thus the validity of a single selection measure may be established in a multi-criteria validation study.

This approach is illustrated in the following instance using the same example shown in figure 3 on the previous page. In this instance, the three local selection measures (the spatial, attentional capability and psychomotor tests) are validated against criteria (either global or local) collected at the end of each of the three stages of pilot training (Basic Flying Training, Advanced Flying Training and the Operational Conversion Unit). Although each test will have been designed specifically to predict at a certain stage of training, it is not necessarily the case that all three tests will predict equally well at each stage of training.

Hypothetically, it might be found that psychomotor tests predict only at Basic Flying Training, attentional capability tests predict at both Basic Flying Training and Advanced Flying Training whilst spatial tests predict at Advanced Flying Training and Operational Conversion Unit. This hypothetical relationship is expressed in table 4 overleaf.

	CVT	SMA	INSB	Digit Recall	Vigilance
Aerobatics	.23	.15	.03	.02	.28
Captaincy & Airmanship	.12	.07	.04	.15	.24
Capacity	.04	.08	.14	.27	.28
Formation of Flying	.15	.12	.01	.03	.20
General Handling	.11	.15	.04	.02	.24
Instrument Flying	.06	.21	.14	.07	.25
Low Flying	.14	.06	.02	.07	.23
Navigation	.01	.10	.00	.23	.31
Night Flying	.02	.15	.11	.13	.28

Table 3 *Correlations of Pilot Tests with Criteria (correlations of 0.15 [moderate] and above are highlighted)*

TEST	Basic Flying Training	Advanced Flying Training	Operational Conversion Unit
Spatial		✔	✔
Attentional Capability	✔	✔	
Psychomotor	✔		

Table 4 Multi-Criteria Validity Matrix

There is a danger that such multi-criteria validation studies can become highly complex and some method is required to collate the information contained within each cell of the matrix. Information concerning the validity of selection measures ***within*** the different stages of training may be used to determine the weighting placed on each selection measure. However, some method of indicating the relative importance of tests ***between*** the various stages of the training system should also be incorporated. There are a number of different methods of achieving this. The percentage of students who recourse or fail at each stage of training will give an indication of the need for high calibre students on the course. Alternatively, subject matter experts (e.g. course instructors) may be used to assign a percentage weight to each stage of training to indicate the extent to which 'high calibre students are required'. Finally, the importance may be indicated in financial terms by simply referencing the overall cost, per student, of each stage of training.

The main advantage of multi-criteria validation studies is that the value of selection tests is judged from more than one point in the training system. Therefore, tests which are deemed not to be valid and regarded as of no use to the selection process for one stage of pilot training will not be discarded if they prove valid for another stage. The procedure may be also used to determine the effectiveness of aptitude tests for different streams of pilot training. A multi-criteria validation which uses validation points beyond the Fast Jet, Multi-Engine and Rotary Wing streaming point may identify tests which are more effective at selecting these different types of pilot.

There are a number of issues which should be noted concerning streaming for Fast Jet, Multi-Engine and Rotary Wing at the point of selection. Recent research by Hobson (ref 6) indicates that at the Operational Conversion Unit level, instructors perceive no significant difference between the three different pilot streams with regard to aptitude selection. Indeed, it is unlikely that selection tests are sensitive enough to differentiate between different types of pilots so far into the training system. Decisions concerning candidates' suitability for specific streams of pilot training should not be based on aptitude scores alone. However, the training pattern post April 1995 (figure 2) indicates that pilot streaming will occur much earlier than before and there may, in the future, be an organisational need to stream pilots at the point of selection. If this becomes the case then a multi-criteria validation study may provide information which could be useful. It remains a future tasking to decide upon a procedure for summarising test validities over two or more validation points at different stages of training.

Potential Practical Difficulties

There are a number of further issues concerning multi-criteria validations which should be noted. These are practical issues which concern the effects of collecting data on an individual throughout different periods of their training. As a sample of students passes through the training system a number will fail at each stage of training. These failures may go to different parts of the pilot Flying Training pattern, enter Ground Training or even leave the RAF. The attrition rate will be generally higher in earlier stages of training and therefore the concentration of high calibre students will increase in later stages of training. This makes the distinction between good and poor students more difficult further into the training system compared to the initial stages of training. Moreover, the sample size in the later stages of training becomes smaller as students fail and the training pattern diversifies to meet diverse operational requirements. It therefore takes longer to collect a large enough sample of data from later stages of training; meanwhile the selection system and training pattern may have changed rendering the resulting validity coefficient meaningless.

These problems do not rule out the validation of aptitude tests using Advanced Flying Training or Operational Conversion Unit as criteria. However, a meaningful validation of aptitude selection tests against operational performance criteria collected several years after the point of selection would be difficult.

The Use of Concurrent Validation Studies

One solution would be to validate tests using a concurrent validation study. This method simply involves assessing a sample of students currently in flying training using the current aptitude tests. Their scores on the tests would then be compared with a relevant criterion to produce a validity coefficient. The main advantage of a concurrent validation is that it provides a relatively rapid indication of the effectiveness of a selection measure and may be used to solve a number of the problems discussed so far.

This method is most useful for assessing the validity of experimental tests which may be required quickly by the organisation. Students at an appropriate stage of training may be used as subjects for such a study which may involve either

global or local criteria. However, a number of points should be noted concerning concurrent validation studies. Firstly, the motivation of subjects may have a large effect on performance during aptitude testing. Secondly, the results from a concurrent validity study may not always be representative of the results of a predictive study because the training system which the students have undergone may affect their scores. For example, INSB, one of the current Pilot Aptitude test, has a strong resemblance to instrument reading as required in flying training. Therefore, training experience could confound the result of concurrent studies when the actual test content and the training course content are very similar. This means that the issues concerning the context of the study are as relevant for concurrent validation studies as they are for predictive validation studies. Finally, the statistical problems associated with using small sample sizes and data context should be not overlooked. Corrections for statistical artefacts may need to be applied. Despite this, the concurrent validation of pilot aptitude tests is feasible and, with the co-location (or close location) of a number of Flying Training schools with the Officers and Aircrew Selection Centre at RAF Cranwell, would not be costly.

Bespoke Data

There may be a perceived requirement to validate a test at a training point where currently no criterion data exists or where more relevant criterion data is desirable. In this case, criterion data may be generated specifically for a validation study. There may prove useful in certain unassessed parts of the training system which are perceived to be highly troublesome and where there is thought to be a selection solution. Furthermore, bespoke data can provide a rapid and accurate estimate of a selection measure's validity, especially when used as part of a concurrent validation. It also has the advantage of being tailored by the researcher with specific selection measures and an informative criterion in mind. Thus, it has the potential to fit well into the validation model in an attempt to arrive at a highly accurate estimate of selection measure validity.

Bespoke data collection requires the assessment of the student by an individual who knows that student's performance well and who is in a position to make an objective rating. Although a course instructor is the individual most likely to be in this position, peer ratings (i.e. other students on the course) could provide reliable and consistent assessments of performance. However, in the flying context, peer evaluations might be difficult since students rarely fly with each other and their assessments may lack credibility in the eyes of decision makers.

Moreover, in practice, the collection of bespoke data needs to be carefully implemented to avoid possible pitfalls. For instance, the use of bespoke data can be a time consuming and costly process and may add little to the information already available from established assessment procedures.

7. CONCLUSIONS

This paper presents part of the current RAF aptitude test research and development programme by addressing the ability domain structure currently employed for aptitude testing and a number of commonly encountered problems associated with the criterion used in validation studies.

Test validation is a crucial part of aptitude test research and development. The traditional choice of validation criteria has been pass/fail outcome at Basic Flying Training. This was mainly due to the criterion's availability and its central place in the flying training system. A clear understanding of the training pattern and how the criterion assessments are derived is necessary. Direct consultation with the assessors is desirable in an attempt to understand, from source, the workings of criterion assessments and then to assess the relevance of each criterion.

An assessment of the overall training pattern may offer alternative sources of validation criteria, suggest which parts of the training pattern may be collapsed into a single criterion and where a criterion should be split for the purpose of studies.

Any influences on the training system which may affect the chosen criterion should be understood and analysed. This includes any relevant changes in policy, demographics, and training procedures. If possible, changes within different time periods should be identified so that any fluctuations in the data may be determined and the consistency of data established.

The use of a domain centred approach validation model will make some of the problems explicit and ensure that there is an established relationship between criteria and selection measures. This will derive the best estimate of true validity coefficient within the constraints of the organisation.

ACKNOWLEDGEMENTS

We would like to thank Dr Jonathan Bradshaw and Christian Hobson for their contribution to the development of the domain centred approach and the validation model for the RAF aircrew aptitude testing.

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SELECTION OF FUTURE FIGHTER PILOTS

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SUMMARY

A new concept in selection of the future fighter pilot generation was created in 1992 by the Surgeon General of the German Air Force. In addition to the basic medical, physical, and psychological examination at the German Air Force Institute of Aviation Medicine (GAFIAM) at Fuerstenfeldbruck the natural, unprotected, relaxed G-tolerance of the healthy young men, which have passed the examination successfully, was determinated in the human centrifuge on a voluntary basis.
In connection with the consideration of the medical and psychosomatic findings just before and during the determination of the G-tolerance the individuals were scored. Based on this score three categories were established as recommendation for a possible pilot career of the candidates in high performance aircraft.
The mean age of the 304 pilot candidates was 20 ± 1.6 years. They reached a relaxed, unprotected G-tolerance of $4.6 \pm 0.5\ g_z$. The classification of this evaluation, with regard of the heart rate and mental stress reaction signs, of the last 129 of these 304 candidates, was: 45 „especially qualified“, 75 „qualified“ , and 9 „less qualified“. The score of the first 22 re-evaluated candidates during the G-training course in Koenigsbrueck about two years later showed no major change in the score in comparison with the first screening results.
These first findings in the comparison of the results of the early phase evaluation and the G-tolerance during the G-training course allows to suppose, that the selection of pilots, added by the human centrifuge screening methods, offer a new chance to make the screening more effective and reach both: satisfy the candidates, and the German Air Force.

INTRODUCTION

Since October 3rd 1990 the German Air Force is in possession of the modern human centrifuge (HC) at Koenigsbrueck near Dresden, Saxony. With this G-force simulation device the Office of the Surgeon General took the occasion to establish a new basic program for the German Air Force at the end of 1992. This program includes the preselection of young pilot candidates for the new fighter pilot generation on a voluntary basis, to optimize the medical selection and to exclude candidates without normal physiological cardiovascular reflexes against acceleration forces.

The demand of the use of a human centrifuge became urgent for the GAF during the preparation phase for the fighter pilot generation of the European Fighter Aircraft respectively the European Fighter 2000, or other high performance fighter aircraft of the next generation.

METHOD

Selection of pilot candidates

The intention of the selection and screening procedure is, to use the fact, that some young, healthy men have the advantage due to their physiological and anthropometric data, to withstand G-forces more likely than other. But not only the well known anthropometric data like a short eye-heart distance might be important for future high G-resistant pilots, but also and especially the cardiovascular response on G-acceleration forces is most important. The knowledge of an active flight surgeon let us know, that even tall pilots may have an excellent natural and operational G-tolerance.

Paper presented at the AMP Symposium on "Selection and Training Advances in Aviation", held in Prague, Czech Republic, in May 1996, and published in CP-588.

Consequently in connection with this consideration it seems to be necessary, to determine the natural, unprotected G-tolerance of the pilot candidates before entering a possible fighter pilot career. A longitudinal survey of findings during selection rides on the HC and results during basic training of pilot students, later of pilots of high performance fighter aircraft, should be helpful in optimizing the selection of the future fighter pilot generation. Not only the plain G-tolerance might be good enough for a recommendation for the pilot career, but also the psychosomatic reaction and excitation before and during the examination in the narrow cockpit of the HC.

With regard of the heart rate and mental stress reaction signs the reached unprotected, relaxed G-tolerance of the pilot candidates was scored. Based on this score three categories were established as recommendation for a possible pilot career of the candidates in high performance aircraft:

- „especially qualified“
- „qualified“
- „less qualified“.

Evaluation in the human centrifuge

The common objective of screening, selection, and examination with the HC is to ensure, that both the candidate and the examiner get information about the individual actual acceleration tolerance and the conclusion, what that means in respect of the personal health, pilot career, and flying safety. Therefore, not only centrifuge rides were offered at Koenigsbrueck, but always an overview upon the whole acceleration physiology, like aerobic and anaerobic muscle and cardiovascular training, nutrition and life style, and psychological training aids, even for candidates.

Common for each candidate is the following procedure in the gondola of the HC:

- Briefing about acceleration physiology, the effects of acceleration forces to the human organism, especially the cardiovascular system, and the instructions for the actual profile on the HC,
- medical examination including ECG, blood pressure, oral temperature, and physical examination by the flight surgeon or physiologist before each exposition in the HC,
- at the start and after the end of each profile the candidate or pilot has to answer green diode-light signals, which illuminate stochastically at the peripheral light bar. The interval-time varies between 600 ms and 1200 ms. The reaction time and the faults (the answer must be given between the minimum of 100 ms and a maximum of 1000 ms) were recorded and are useful to compare the situation awareness before and after each run on the HC,
- during evaluation the ECG, the ear-pulse, the respiration frequency, the voice communication, and the video signal are monitored and recorded. The reaction time will be measured during all passive runs. The correct answer within the time limit to the green illuminating diode-light at the light bar in the periphery is a good method to get objective indications of the alertness of the candidate. The light signals were presented at g-levels above +1.6 g_z,
- the first typical profiles for each individual on the HC are the warm-up-run profile EP 01 (Fig. 1) and the gradual G-increase profile LP 01 (Fig. 2). These two profiles are realized in the automatic mode (AM) of the HC and are always the first profiles for each candidate, student-pilot or pilot. This interval-profile EP 01 will give a first impression of the peculiarity of the HC and is a common preparation for the following profile, the determination of the individual natural unprotected G-tolerance with the linear profile LP 01,

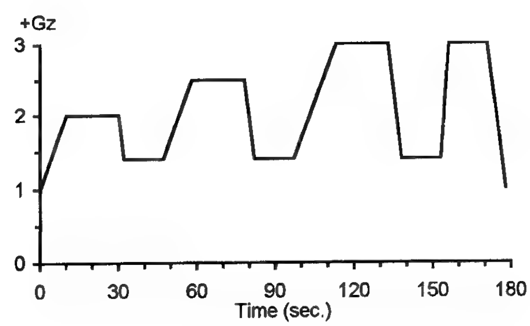

Fig. 1:

warm-up-run profile EP 01:
first 3 onset: 0.1 gs^{-1}, last onset 0.5 gs^{-1}
offset: 0.3 gs^{-1}, first 3 plateaus 20 s, last 15 s.

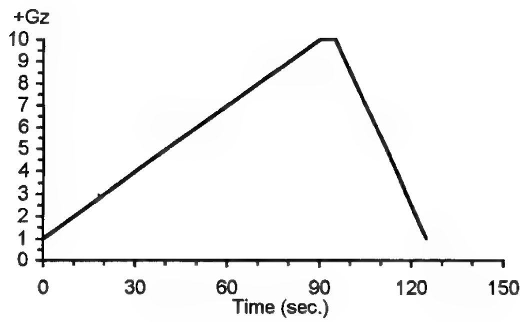

Fig. 2:

linear profile LP 01: gradual onset: 0.1 gs^{-1}
gradual offset: 0.3 gs^{-1}

- each profile will start on the 1.0 g_z basis, but during the profile itself the lowest G-level remains by 1.4 g_z, the „idling speed" of the HC. The reason is to reduce further more unnecessary coriolis effects during deceleration,
- the deceleration of the HC after normal and emergency termination of any profile will be -0.3 gs^{-1}, with the experience, that a smoother deceleration is more protective than a rapid deceleration in case of cardiovascular disturbances. The „lost" time during a smooth deceleration is more valuable than the disadvantage of a rapid deceleration with blood pooling on the right heart side due to the reflux, the decrease of the heart rate, and the additional coriolis effect,
- medical examination including, ECG, blood pressure, and physical examination by the flight surgeon or physiologist after each exposition in the HC,
- individual debriefing.

Each profile may be terminated either by the candidate in the gondola himself by releasing the stick or releasing the „dead mans button", or by the medical responsible physician at the medical monitor console, or the chief engineer. There is altogether a fourfold redundancy for safety reasons.

Natural G-tolerance of pilot candidates

During the first examination of pilot candidates in the GAF Institute of Aviation Medicine at Fuerstenfeldbruck physiological and psychological abilities with clinical methods are used for the decision, whether the candidate is physically and mentally healthy to start a pilots career. The special qualification for operations in a high-g environment cannot be detect with common clinical methods. Therefore the examination of the natural, that means „relaxed, passive, and unprotected" G-tolerance might be an additional item to select especially qualified young candidates for the career in a high performance fighter aircraft.

The examination includes:

- Briefing about acceleration physiology, the effects of acceleration forces to the human organism, especially the cardiovascular system, and the instructions for the passive evaluation in the HC,
- starting with a „warm-up" interval-profile EP 01 (Fig. 1),
- followed by the linear profile LP 01 (Fig. 2) with a gradual onset of 0.1 gs^{-1},
- determination of the natural g-tolerance by using either the individual symptoms answered verbal by the candidate (grayout, tunnelvision), or monitored symptoms like depression of the ear pulse curve, more than two wrong (e.g. inadequate) reactions upon the light diodes, or typical visual findings on the video monitor.

There is neither active nor passive anti-G-protection.

The evaluation includes the following criteria:

- natural G tolerance:

3.5 to 3.9 g_z :	2 points
4.0 to 4.6 g_z :	4 points
> 4.6 g_z :	6 points

- heart rate during the preparation phase (during the time, when answering the light signals before starting the first profile):

> 120 min^{-1} :	0 points
100 to 119 min^{-1} :	1 points
80 to 99 min^{-1} :	2 points
< 80 min^{-1} :	3 points

- heart rate at the end of the 3 g_z plateau during the warm-up run profile:

> 160 min^{-1} :	0 points
140 to 159 min^{-1} :	1 points
120 to 139 min^{-1} :	2 points
< 120 min^{-1} :	3 points

The qualification result will be:

especially qualified: 9 to 12 points
qualified: 6 to 8 points
less qualified: < 6 points

Natural G-tolerance of student pilots

During the first physiological training course the pilot students were re-evaluated on the HC at Koenigsbrueck at the beginning of their G-training. The unprotected, relaxed G-tolerance will be determined in the same manner like during the screening evaluation, when they were pilot candidates. The student pilots, now about 2 years older, with the experience of 20 flying hours on the beach bonanza aircraft, will be scored again in the same procedure and ranked:

- „especially qualified"
- „qualified"
- „less qualified".

RESULTS

Natural G-tolerance of pilot candidates

Since April 1993 the screening and selection of pilot candidates were carried out with the HC at Koenigsbrueck. 304 pilot candidates until May 1996 were examined:

The results of these 304 candidates:

Mean age: 20.0 ± 1.6 y (17 ... 29 y)
mean height: 180.9 ± 5.1 cm (162 ... 192 cm)
mean body mass: 73.8 ± 7.2 kg (53 ... 97 kg)

The natural, relaxed G-tolerance:

$4.6 \pm 0.5\ g_z$ (3.3 ... 6.1 g_z).

The qualification results of the voluntary, since 1995 with the new score „ranked" 129 of these 304 pilots candidates:

- especially qualified: 45 (34.9 %)
- qualified: 75 (58.1 %)
- less qualified: 9 (7.0 %)

Natural G-tolerance of student pilots

Since November 1993 the natural G-tolerance of student pilots at the beginning of their training course with the HC at Koenigsbrueck was determined. 198 student pilots until May 1996 were examined:

The results of these 198 student pilots:

Mean age: 22.8 ± 1.8 y (20 ... 27 y)
mean height: 180.3 ± 5.4 cm (168 ... 191 cm)
mean body mass: 76.5 ± 7.8 kg (58 ... 98 kg)

The natural, relaxed G-tolerance:

$4.7 \pm 0.6\ g_z$ (3.5 ... 6.2 g_z).

Natural G-tolerance of pilot candidates in comparison with their G-tolerance, when student pilots about 2 years later

The G-tolerance and the score of the first 22 student pilots now can be compared with their G-tolerance and score during their G-tolerance evaluation. Between July 1993 and September 1994 22 pilot candidates were examined and scored at Koenigsbrueck. About 2 years later, the same 22 young men, now student pilots, were scored at the beginning of their G-training course during the basic physiological training course between June 1995 and May 1996.

The qualification results of the same 22 candidates (C) respectively students (S):

Mean age (C): 20.7 ± 1.7 y (18.4 ... 24.0 y)
Mean age (S): 22.6 ± 1.7 y (20.7 ... 25.9 y)

The natural, relaxed G-tolerance:

C: $4.7 \pm 0.4\ g_z$ (4.0 ... 5.3 g_z).
S: $4.9 \pm 0.6\ g_z$ (3.9 ... 5.8 g_z).

Heart rate during the preparation phase:

C: $103.1 \pm 21.1\ min^{-1}$ (66 ... 144 min^{-1})
S: $94.2 \pm 18.0\ min^{-1}$ (62 ... 142 min^{-1}).

Heart rate at the end of the 3 g_z plateau during the warm-up run profile:

C: $143.3 \pm 20.9\ min^{-1}$ (103 ... 186 min^{-1})
S: $133.1 \pm 22.3\ min^{-1}$ (98 ... 180 min^{-1}).

The qualification result:

especially qualified:	C: 9 (41 %)	S: 14 (64 %)
qualified:	C: 10 (45 %)	S: 5 (23 %)
less qualified:	C: 3 (14 %)	S: 3 (14 %)

The qualification score:

points:	Candidates:	Students:
4:	2	2
5:	1	1
6:	5	2
7:	4	2
8:	1	1
9:	4	4
10:	0	2
11:	2	6
12:	3	2

The individual comparison with the numerical scoring points between the evaluation during the screening runs, when pilot candidates, and the evaluation, when student pilots, shows, that the „less qualified" candidates are the „less qualified" student pilots too. 7 of 22 individuals were scored less during the evaluation, when student pilots, but only 1 of the „especially qualified" candidates was ranked „qualified" with 1 point less during the evaluation, when student pilot.
The experience of 20 flying hours and the passed selection procedure are reflected by the increase of „especially qualified" score results up to 64 %.

CONCLUSION

This qualification results however will be only an additional value for the screening method to get a new fighter pilot generation. We expect to get better information of the usefulness of this evaluation perhaps after five to ten years, when the candidates are licensed pilots. We know very well, that g-tolerance measurements in the early phase of the pilot career will not be able to predict the qualification of an excellent fighter pilot. But we think, that even the finding, that one individual seems to be really not qualified for the high-g environment, is good enough, that the candidate will use this finding to choose an alternative profession, or a transport aircraft pilot's career.

DISCUSSION

The human centrifuge at Koenigsbrueck, primarily constructed for medical research and diagnostics, is now in service preponderant for pilot candidate selection and student pilot training. The results of the G-tolerance evaluation are still recommendations. In addition to the G-tolerance evaluation: Motion sickness problems in the HC at Koenigsbrueck occur less than 0.1 % of all centrifuge-runs. This phenomena may be explained by the logical consequence of the 10 m arm of the gondola and the active three degree of freedom active gimbals system. Consequently each motion sickness problem during the evaluation or the training in the HC should be recognized as a medical or psychological symptom, that has to be clarified. Poor G-tolerance or even a pathologic G-tolerance may be detected in the HC early enough, so that firstly further medical diagnostics could be done, before the wrong and unsuccessful way of an expensive pilot career starts.

Also under discussion is the question, if the up to now voluntary evaluation of the natural G-tolerance of the young pilot candidates should be mandatory. The question, if the results of the evaluation should determine or at least influence the selection of this 18 to 20 year old male population for future qualification for agile fighter aircraft, may be answered perhaps after a period of 5 years. The first results of this longitudinal study are the first encouraging steps on this track. Then the self control of our judgment of today may be possible.

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FLYING TRAINING - PAST ACHIEVEMENTS AND FUTURE CHALLENGES

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SUMMARY

The cost of modern combat aircraft requires that they are operated safely in peacetime. Equally, the nature of air operations demands their aggressive operation in war. The challenge is to recruit people who can satisfy these 2 differing requirements. Moreover, this has to be done against a background of the difficult recruiting, manning and experience issues facing many modern Air Forces. The challenge is to identify and train effectively the correct number and balance of fighter pilots for the 21st Century.

INTRODUCTION

I would like to address briefly the main issues facing the training organisations of most NATO Air Forces as they move towards the 21st century. My aim is to highlight the difficulties, or as the new managementosi would term them - challenges, that we have to face. Those of you who know me will be aware that I have no qualifications to speak to you today other than a lifetime spent trying to improve my own, and other peoples', fighter flying skills.

HISTORY

Let me start with a little history. This is a picture of the RAF's Number 37 Advanced Flying Training Course. The picture was taken over 25 years ago. Let me remove first the instructors and those that failed the course. We are left with 14 fresh-faced young men on the threshold of their military career. Yet, within a few years, 5 were to kill themselves in aircraft accidents. Remember, this was peacetime, yet we still suffered 36 percent losses.

No Air Force can contemplate today attrition rates on this sort of scale - and we are doing better. In 1970, the RAF killed about 4 people for every 100 000 flying hours, or roughly one person ever 2 or 3 weeks. Today, we have halved that figure. Nonetheless, the reality of today's statistics is that, if the average frontline pilot flies 3000 hours in his Air Force career, and that is probably pretty typical, then he has roughly a 1 in 20 chance of being killed in an aircraft accident. These are not the sort of odds that we should willingly be accepting - and the psychologists among you might be wondering at the sanity of anyone who does willingly volunteer to accept such statistics.

So one part of our selection and training has to focus on reducing our accident rates - and this has, inevitably, particular prominence in peacetime. But, reducing our accident rates is only one part of the equation.

The other part is to create a fighter pilot who will go out and actively engage the enemy. We are not looking for good infantrymen or nautical officers who fight alongside their fellow man and so may garner some strength and determination from other people's presence. Our man or woman has to be ready to fight alone. This requires different attributes and very different styles of leadership.

Let me slip back and look at some of the great fighter pilots from the past. The results may surprise you!

Max Immelmann, who had a combat manoeuvre named after him, was described as 'having a truly childish temperament'. Georges Guynemer, the French ace, was too frail for the infantry or the cavalry, suffered symptoms of tuberculosis and was so delicate that he fainted on parades. William Bishop was saved by the outbreak of war from being sent down from the Canadian Royal Military College for being 'the worst cadet ever' and 'a rebellious brawler and hopeless scholar'. He went on to become Air Marshal William Bishop VC CB DSO and Bar MC DFC Chevalier of the Legion of Honour and Croix de Guerre with Palm.

Mick Mannock, the British ace, was so badly treated in a turkish jail that he was unfit for military service. He was blind in one eye and

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suffered nausea from fear so badly that, at one stage, he was accused of cowardice. Manfred von Richthofen failed his first examination and crashed on his first solo. Had he been removed from pilot training, 80 allied pilots would not have fallen victim to the Red Baron. And finally, Eddie Rickenbacker, the greatest of the American aces, was described as a 'crude roughneck' and 'the most unpopular man alive'.

It all seems pretty straightforward. We just need to recruit frail, one-eyed immature misfits who are afraid of flying and not too intelligent!

Alright, I am being flippant. But we should not dismiss these protagonists from the past out of hand. They went through the one great selection process that we are unable entirely to emulate - actual combat. These aces survived in the toughest of all selection procedures. And survived against the toughest of odds. The French lost 77 percent of their total aircrew throughout the war. The United States lost half the pilots that it sent to Europe. For the British squadrons early in the war, it was estimated that, for every 20 pilots who left for France, one would return to see England again. How would our professional Air Forces today fare in this arena? Would they accept such long odds on survival?

Our aim has to be to recruit people who would accept these odds, in extremis, and if their country demanded it. But does our modern culture encourage such self-sacrifice? Is it possible to create and maintain the standards of Sparta within our military establishments when materialism and the welfare state are nurturing a softer product outside? The contrast between the 2 cannot be too stark, yet we have to remember that our potential enemies often come from societies far harder than our own.

RECRUITING CHALLENGES

Moreover, we also have to recruit from these softer climes. Let us look at a few facts of life for an Air Force trying to encourage the cream of the Nation's youth to man its fighter force.

First, for Britain and probably for a number of other nations, the pool from which we fish is smaller. This graph shows the mean number of 18-20 year-olds in our population from 1972 to 2001. In 1991, we had some 3.5 million men and women in our target population. Today, the figure is nearer 2.75 million - and is set to stay around this number until well into the next century.

Next, we have to accept that computers, televisions, videos and personal hi-fis (which incidentally suggest that half our volunteers will already have impaired hearing) mean that, while our potential recruits may be considerably more healthy medically, they are also almost certainly less fit physically than their predecessors. The British Army has had to lower its initial fitness standards, relying instead on additional fitness training after entry. Modern fighter designs and capabilities demand that we have only the highest levels of physical fitness in the cockpit. If we can no longer recruit close to this level of fitness, then we must include time to develop it during training.

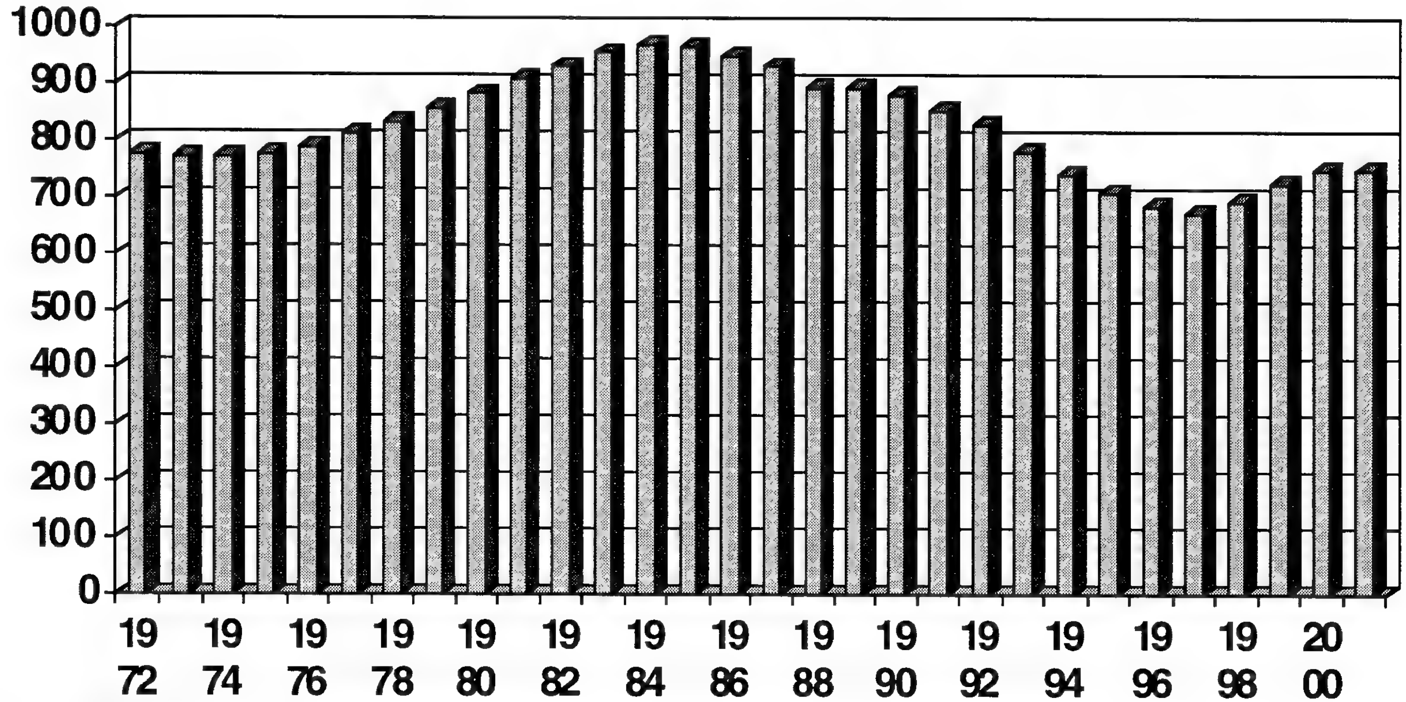
Let me talk briefly about intelligence. Genius or great intelligence was not a notable feature in any of our early aces. Richtofen, Bishop and, perhaps most of all, Rickenbacher were actually noted for their lack of scholarship. Given the complexity of modern aircraft, do we need greater intelligence today? Certainly, we need a bright mind that can grasp the essentials of aircraft operation in the widest sense - but this does not necessarily equate with academic achievement.

Give me a reasonably bright enthusiastic teenager and I will hand to you 5 years later a more potent fighter pilot than can be produced via any seat of academic learning. This is not to decry the product of the universities or to deny the need for intellectual ability in our officers and, particularly, future leaders. Merely to question the value of university education for frontline fighter pilots.

Take my own Air Force. For reasons that have more to do with financial expediency than a search for excellence, the RAF has elected to recruit 70 percent of its pilots from universities and to take only 30 percent from other sources. This graph shows the percentage of our target population that have, over the years, had a university education. As you can see, we are currently running at just under 25 percent entering university. About 17 percent of these undergraduates will fail their degree course. Turning this percentage into numbers gives a less impressive picture. Because of the dip in our demographic graph, the number of undergraduates in Britain is actually falling.

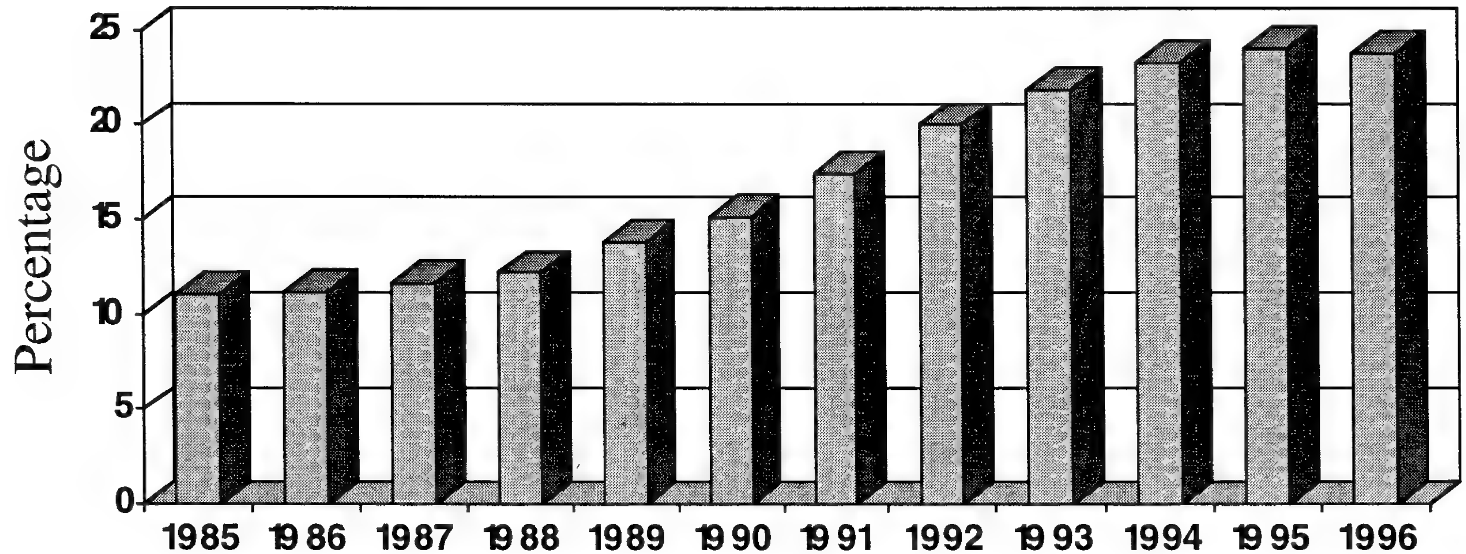
Of more interest though, is that we have chosen to recruit 70 percent of our pilots from the 20 percent of the population who obtain a degree and only 30 percent from the other 80 percent of the population.

Population as an average of 18-20 years



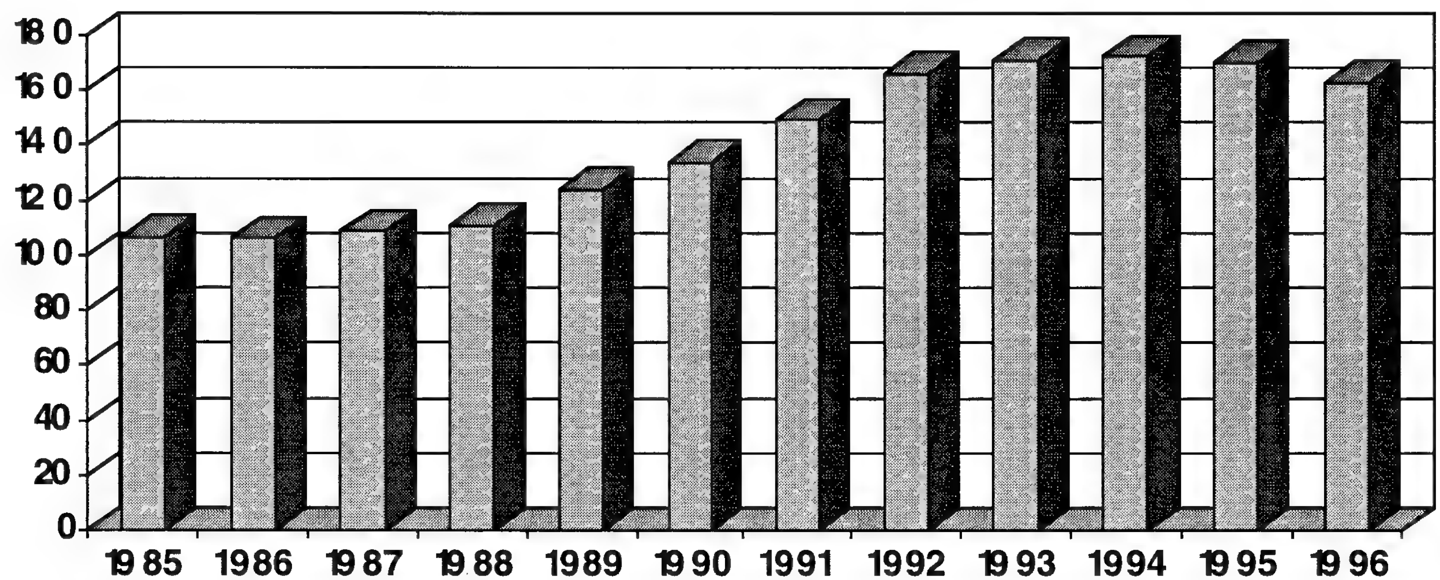
Strike Flight Safety

Degree Under 21 Participation
GB Institutions



Strike Flight Safety

Number of undergraduates aged 21 or less



Strike Flight Safety

This has led to some fierce competition for non-university places and only those with particularly high scores are being accepted. There is less competition for the university entrants and, often, their scores will be lower. In the past, the university and RAF College entrant were seen as the cream that would go on to higher rank. The decision, these days, to recruit so many graduates risks undermining this arrangement. The cream may now be found in the 30 percent who do not have a university education and who, incidentally, do not have to spend 3 years at university. As a result, they are on their first squadron sooner, eligible for specialist courses sooner and, surprise, in line for promotion sooner. It may be, in the future, that a university education is actually a drawback for those attempting to reach the highest rank.

Let me move on and discuss the motivation for our youth to enter military service. Clearly, fighter aircraft are potent instruments of war that continue to provide thrills and excitement on a scale impossible to even the most sophisticated roller coaster. This has to provide encouragement, at least for some, to fly fighter aircraft. But do we want such sensation seekers?

Maybe not - but we are different in this respect to the Army and the Navy. Many people join the Air Force, no matter how much they dress it in other issues, because they want to fly. This is the passion that takes them towards a military cockpit with all its discomforts. Yet a passion to fly may not lie easily with the responsibility, self-discipline, capabilities and loyalty that we need in our modern cockpits.

There are other recruiting challenges. The military are no longer always seen as the cowboys wearing the white hats. The details of our commitment to messy wars in under-developed countries were once, because of the limitations on communication, not easily available to the general public. Now they are brought almost instantly to every home by CNN, and analyzed immediately in the sort of sound bite routine that has to label everything as either 'Right' or 'Wrong', 'Good' or 'Bad'. Many middle-class mothers watching these nightly snatches at reality do not see a career for their darling offspring. Far better, a safe job in the City at 3 times the salary and a Mercedes in the driveway. Add to this Belgian army colonels indicted for failing to protect their troops adequately in Rwanda and Italian pilots jailed for ejecting from their aircraft following an engine failure and it is hard to find inducements, in this age of litigation, to accept the vagaries of military service.

In spite of all the difficulties, quality young people do continue to come forward to fill our cockpits. For the RAF, one of the benefits of down-sizing (another good management word) is that, not only have we matched the quality of the past, but our intakes today are showing aptitude scores well above the minimum required. Whether this will continue is for others to judge.

TRAINING REALITIES

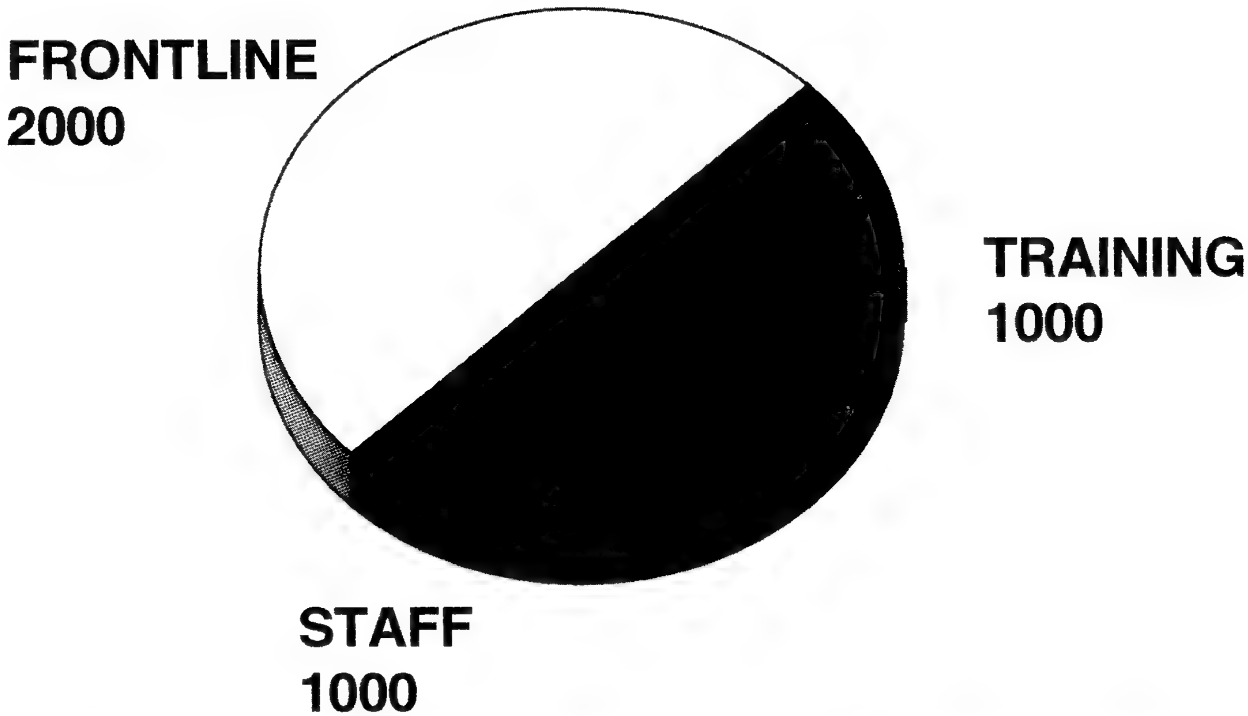
Pilot training is expensive, and to produce a military pilot in a fighter cockpit is very expensive. Let me discuss briefly a few macro issues that need to be addressed, particularly by the smaller Air Forces, before we can safely move to the micro issues.

Let us start with a macro look at an Air Force. The jobs that you may require your pilots to do in the course of their careers are to fly on the frontline, to join the training organisation and teach others to fly, or to join the staff in some headquarters. These staff jobs include everything from Chief of the Air Staff down to the lowly captain involved in the procurement of your next generation weapons. I would emphasise that these are not staff jobs that can be handed to administrators. They require experience and expertise in aircraft operations.

Let us now add the number of pilots involved in each area. These figures are not untypical for a medium sized Air Force, but I have simplified them to keep my mathematics straightforward. There are a couple of points to make. First, unlike other arms of the Air Force, administrators or engineers for instance, pilots have to enter this circle via the frontline at the top of the slide. This provides a natural filter on the number of pilots that you can recruit and train. Next, while there are economies of scale to be had within the staffs, it is difficult to reduce this element of the Air Force below a certain minimum level. Whether you operate 20 or 200 F-16s, you still need an F-16 specialist staff at Headquarters.

Now let us recruit to provide the 4000 pilots needed to run this Air Force. If we bring into productive service, in other words discount the training losses, 250 pilots per year and each pilot stays in the Air Force for an average of 16 years

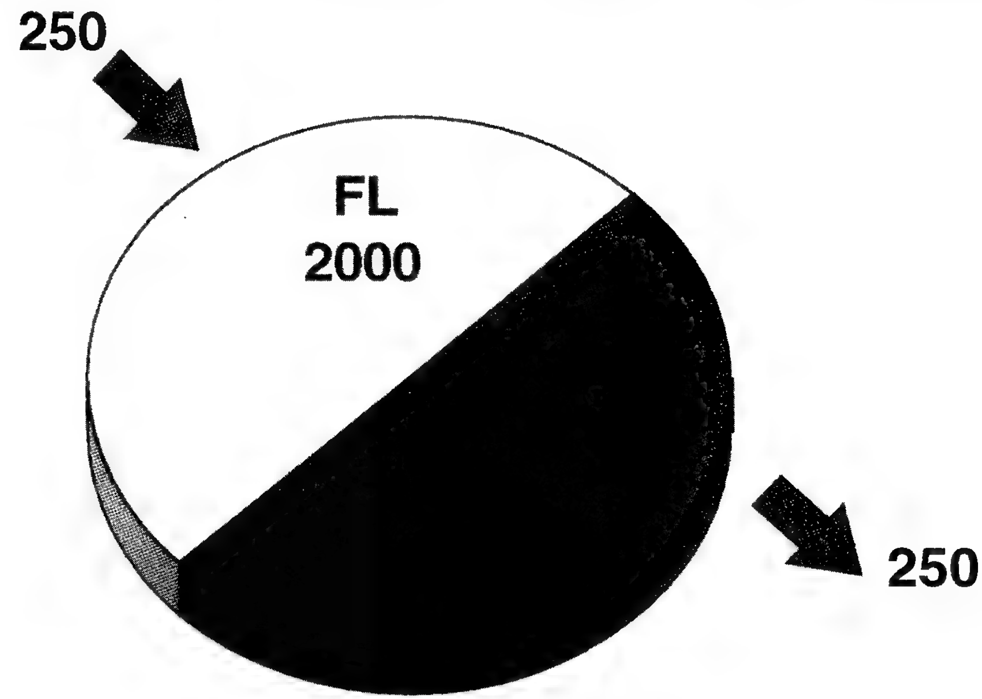
Pilot Employment in Typical Air Force



Strike Flight Safety

Pilot Employment in Typical Air Force

RETURN
OF SERVICE
16 YEARS



250 Pilots x 16 Years Service = 4000 Total Strength

Strike Flight Safety

then, Eureka, we have a nicely balanced Air Force.

The problem comes if the variables start to change. Let's say that the failure rate in the training establishments increases and, as a result, you bring into productive service 10 percent less pilots. You are now 25 pilots adrift. Do it a second year, and you are 50 pilots short. Where do you carry this shortfall? You cannot reduce the staff without affecting airworthiness and other issues. If you move people from the training machine to the frontline to maintain operational capability, then you reduce your instructor numbers and so your ability to produce sufficient trained pilots for the future - thus continuing the downward spiral.

Difficult decisions - but as nothing compared to the greater dilemma faced by some Air Forces. The critical figure in all these calculations is dwell time - the return of service after training. The airlines in the USA, Great Britain and, no doubt, many other nations are recruiting - and one of the best sources of pilots is the military. Hard figures are difficult to find but I have heard suggestions that the US airlines will require 5000 pilots between now and the year 2000, and that British Airways alone will be recruiting some 200 pilots a year until 2005. If they poach from the Air Force and your return of service goes down from, say, 16 years to 12 years, the effects are far more immediate and devastating.

You are now not 25 or 50 pilots short but, potentially, hundreds of pilots short - and short across the whole spectrum of experience. Moreover, there are difficulties if you increase the number of pilots that you introduce into productive service to compensate. First, there is the delay as the training machine kicks into a new gear - and an obvious question here is where are your instructors coming from to generate this increased output? Pilots with the experience to be instructors are just what the airlines are looking to recruit. Secondly, there is the natural filter of the frontline. Post too many new pilots to your frontline squadrons and, inevitably, experience levels drop - and you risk more accidents and less operational capability.

There is one more obvious variable that we can play on this model Air Force and that is to change the Threat. The disappearance of the Warsaw Pact, the crumbling of the Berlin Wall and public demand for a 'Peace Dividend' can equally destroy a well-planned Air Force structure.

Let us settle for a modest 20 percent reduction in the frontline - and several Air Forces have had to take cuts significantly larger. An immediate effect is that you have to turn off or reduce the 250 pilots coming into your frontline each year from training. The problem is that there is already a queue of people in the training machine. Stop the flow and they bunch up causing what the RAF calls the training backlog and the USAF calls the bathtub effect.

For the USAF, because of the scale of their Air Force, it is no more than a bathtub in their statistics. For smaller Air Forces, the effects can be more long term. For the RAF, after our drawdown of the early 90s, we had in backlog in March 1994 274 aircrew of all disciplines and, at the start of this year, 210 pilots still held up somewhere in the training machine.

This slide shows our non-graduate pilot applications and selections for the period 1991-1995. The figures provide a coarse measure as we were actively discouraging people from applying for pilot training over the period. Nevertheless, look at the low number selected for pilot training on the right hand side. These low figures may reduce our backlog but they also risk creating problems when we look at the long term manning of the Air Force. Numbers into productive service multiplied by the return of service determines the size of your pilot corps. Numbers of pilots into productive service on this scale are not sustainable in the longer term.

To bring all this together - What are the fundamentals that we can draw from this look at our hypothetical Air Force?

First, that in this whole business we are dealing in extended timescales, both in the time taken to train pilots and in the return of service that we require. Tamper with the macro issues in your manning plan and the after-effects can be long term. Be sure that you know what you are trying to achieve and how you are going to do it.

Next, return of service after training is probably the most critical node in the equation. The move in civilian employment may be away from fixed, long-term contract. But for us, in the military, while I am not advocating 90 year old pilots, we do need people with the commitment to stick with a military career. The other half of this obligation, of course, is that the military also needs to provide adequate job satisfaction and remuneration to persuade pilots to continue to serve.

Lastly, as return of service is so critical, then the

Direct Entry Applications and Selection for Pilot Training

YEAR	APPLICATIONS FOR PILOT TRAINING	SELECTIONS FOR PILOT TRAINING
1991	1492	123
1992	472	58
1993	492	22
1994	455	16
1995	770	48

No of pilots into productive service x Return of service = Total No. of pilots

Strike Flight Safety

age of our recruits and the time it takes them to reach the frontline also becomes decisive. Finish school at 18, university for 3 years and 2 years flying training, and you can be on your first squadron at 23 years of age. Plenty of time to amortise training costs, establish your credentials and start on the career ladder. Double the time to complete flying training, increase the university course to 4 years and leave school one year later, and suddenly your first-tour fighter pilot is 27 years old. More mature - certainly. But war fighting is a young man's game. And where is the scope for learning the trade and gaining experience? In career terms, you need to be looking at Major by your 30th or 31st birthday. Can you sensibly be eligible for promotion to a senior supervisory flying position after only 3 years on your first squadron?

WHAT ARE WE LOOKING FOR?

So much for the troubles and pitfalls of recruiting and training. Let me conclude by giving some of the ingredients that I would like to see us looking for in our future pilots.

Let me start with what I call 'stick and rudder' skills. In the past, when we had aircraft with interesting handling characteristics, it was essential to have pilots with a high degree of coordination to control the beasts. We have moved to the age of 'carefree handling'. A computer now stands between the pilot and the control surfaces, preventing him from doing irrational things that would, in the past, have jeopardised the aircraft. This leaves me with something of a dilemma. Certainly, we need hand/eye coordination in our pilots but do we need still the same levels of skill that were required in the past?. Instinctively, I feel not. The trouble is that, equally instinctively, I sense that the quick-wittedness required in our modern aviator will only be found in the traditional sporty, physically capable individual that we have always sought. I can bring no statistics to this dilemma. Perhaps one of you can provide a more authoritative judgement.

Let me move on to situational awareness. Those of you privileged enough to be at the excellent Symposium at Brussels last year, will be aware of the endeavours and research being done to develop situational awareness in our modern fighter pilots. Certainly, we need on the frontline pilots who can interpret a multitude of data from a variety of sources to provide a picture of the environment around them, then - equally important - make and articulate rational decisions based on this understanding. That is the aim - but are we always recruiting to achieve it?

I sometimes sense that our Air Forces draw too thick a demarcation line between those charged with recruitment and training, and those responsible for the operational units. I was dismayed when I talked to one of our pilot aptitude specialists when he indicated that much of the testing presently undertaken was aimed primarily at predicting successful completion of basic flying training on the Tucano. He went on to add that longer term prediction was more difficult but that we were doing hearteningly well.

Training organisations are interested in training results. Frontline units are interested in operational capability. The 2 requirements are not always harmoniously joined.

I do not want pilots manning NATO's frontline squadrons - I want fighter pilots. This means that, at the selection stage, we should be homing in on those, not just with piloting potential, but also with the potential for maintaining situational awareness. One of the areas for assessing ability to maintain situational awareness, highlighted at the Brussels Symposium, was general cognitive ability. As a lay person, I see this measure of general cognitive ability or, as I would term it, capacity as vital. I am no expert but a superficial glance at the problem would suggest that dual task tests like 'Vigilance' seem to offer a useful way forward in this area.

Finally, before I leave situational awareness, we should not forget that it can be taught. The formal teaching and development of situational awareness in our pilots during their early training may provide immediate benefits in flight safety terms as well as improving operational capability in the longer-term. The software packages are out there - let's use them.

To close, let me move away from selection and training in aircrew terms and concentrate briefly on the other half of the man or woman that we are trying to recruit - the officer and leader.

There are certain intrinsic differences between an Air Force and the other 2 Services. First, as I hinted earlier, for the most part only a small proportion of our officer corps actually engages the enemy. Moreover, they do so alone. There is no General or Admiral saying, "Follow me!". The inspiration for them to go out alone and

aggressively seek combat has to be nurtured in the periods of peace before the battle. This requires different inspirational and leadership skills to, say, the Army officer who can accompany his troops into battle.

Next, more than any other fighting arm, ours is dominated by technology. This means that, not only do our pilots need a high level of technical competence, but that our soldiers, our groundcrew, will be better educated and more questioning. This, in turn, demands a different style of leadership. A problem here is that the Air Forces' squadron system does not provide the same training ground for the junior officer that the Army enjoys with its organisation of companies and platoons. The first time that an Air Force officer may find himself formally commanding troops is as a lieutenant colonel - hardly the time to be learning your trade. Yet, in the final analysis, our Air Force commander has to be as inspirational and credible as his Army or Navy counterpart. We have to ensure that he is chosen with these requirements in mind and adequately trained to meet the command and leadership challenges.

CONCLUSION

Let me wrap all this up by giving you my wish list.

It was Dr Norman Augustine, when he was Chairman of the US Department of Defence Science Board, who said, "In the year 2054, the entire defence budget will purchase just one tactical aircraft. The aircraft will have to be shared by the Air Force and the Navy three and one-half days per week, except for leap years, when it will be made available to the Marines for the extra day".

Since then, economies of scale and the introduction of the 2-tier Air Force have prevented us moving completely towards Dr Augustine's First Law of Impending Doom. Nonetheless, our resources are limited and expensive, vital assets that we need to use effectively in peace and war. The qualities of the pilots at the controls of these war machines will be critical to their safe and effective employment.

So, we need for the NATO Air Forces of the next Century pilots who have a high standard of physical and medical fitness, are intelligent enough to operate effectively some of the most sophisticated machines created by man, bold enough to take calculated risks and possibly die for their Country, yet cautious enough to operate to the highest safety standards in peacetime. Ideally, they should also be modest, diplomats, totally honourable and natural leaders. Is that so much to ask?

SINGLE BEAT LATE POTENTIALS AND THE RISK OF HUMAN FACTOR FAILURE DUE TO THE SUDDEN CARDIAC DEATH

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SUMMARY

Especially due to the catecholamines compartment of stress managing, the microfocal dispersed changes of the myocardium are observed, the result of which is the myocardial electrical instability. In clinic these changes are known as predisposition to the life-threatening arrhythmias and/or to the sudden cardiac death. Late potentials (LP) are considered the manifestation of myocardial electrical instability in the body surface potential distribution within the electrical field of the heart. Standard procedure of late potential extraction is based on signal averaging of 3 ECGs from 200 to 400 electrical systoles, i.e., in the interval of two to six minutes. Discussed limitations are suppressed by developed procedure of LP extraction from single electrical systole. Input data is the matrix of eighty simultaneously measured ECGs and three vectorcardiographic ECGs from single systole. Singular Value Decomposition allows the noise suppression by exclusion of higher order (i.e., over the twentieth) orthogonal components from final signal reconstruction. From the mentioned the hypothesis of the relationship between coping with influence of psychosocial stressors and LP origination was adopted. Data from 48 healthy subjects (mean age = 42.68 years, SD = 14.65) and 29 subjects (mean age = 49.14 years, SD = 19.15) with sustained ventricular tachycardia proved by programmed ventricular electrical stimulation were analyzed. Using the logistic regression 81.82% (81.25% of healthy and 82.76% of subjects with sustained ventricular tachycardia) were correctly classified. Thus, single beat LP extraction appears to be a suitable compartment of methods for the early diagnostic of health risks of influence of psychosocial stressors especially within the subjects with high level of importance of possible risk of human factor failure (as pilots and/or air-traffic controllers).

1. INTRODUCTION

Microfocal dispersed changes of the myocardium are observed (16), especially due to the catecholamines compartment of stress managing. The result of these findings is electrical inhomogeneity leading to myocardial electrical instability. In clinical conditions these changes are known as predisposition to life-threatening arrhythmias and/or to sudden cardiac death. As the next evidence of myocardial electrical inhomogeneity, late potentials (LP) are considered to be the manifestation of myocardial electrical instability in the potential distribution within the electrical field of the heart on the chest surface. This myocardial instability can be verified invasively by programmed ventricular electrical stimulation.

Standard procedure of late potential extraction (2, 10, 17) is based on signal averaging of 3 ECGs from 200 to 400 electrical systoles, i.e., in the time interval from roughly four to six minutes. This procedure does not appear suitable for the investigation of dynamic situations. Its limitations are suppressed by original procedure of LP extraction from single electrical systole.

The purpose of this study is to demonstrate the ability of single beat late potentials (SBLP) to discriminate healthy subjects and subjects with proved sustained ventricular tachycardia. In previous papers (8, 9) the ability of SBLP to discriminate subjects with and without sustained ventricular tachycardia was demonstrated.

Validity of this procedure was verified earlier (8,9) using the data from the subjects exhibiting history of unexplained syncope, by successful discrimination these data into two groups on the basis of result of programmed electrical ventricular stimulation. Accordingly, the hypothesis of the relationship between coping with long-lasting influence of psychosocial stressors and LP origination or evolution was formulated.

2. METHODS

To eliminate the signal deterioration due to signal averaging procedure, ECG signal from single heart beat only was evaluated. Simultaneously measured matrix of eighty surface ECGs and three orthogonal vectorcardiographic ECGs was processed by Singular Value Decomposition permitting necessary noise reduction. The noise reduction has been done by elimination of higher order (above the twentieth) orthogonal components of singular value decomposition from data reconstruction as a final step of singular value decomposition procedure.

To reach the parallelism with (generally known) standard LP, subsequent steps of signal processing and evaluation were kept analogous to the standard late potential extraction (i.e. filtration of data by Butterwoth filter with frequencies 40 and 250 Hz). Standard parameters, i.e. filtered QRS duration (TQRS), root mean square of last 40 msec of filtered QRS interval (RMS40), and time of signal amplitude lower than 40 uV within the final part of the QRS interval (LAS) were determined. Beside this, the morphology of SBLP (i.e. presence of relatively

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separated local peak shape of SBLP) was evaluated. Data evaluation was carried out by stepwise discriminant analysis, logistic regression and survival analysis (system of statistical programs SOLO).

3. MATERIAL

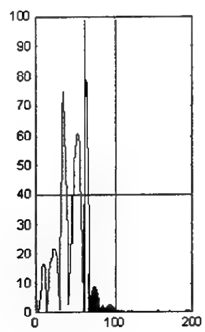
Data from 48 healthy subjects (mean age = 42.68 years, SD = 14.65) (Group I) and 29 subjects (mean age = 49.14 years, SD = 19.15) with sustained ventricular tachycardia proved by programmed ventricular electrical stimulation (Group II) were analyzed.

4. RESULTS

Using the stepwise discriminant analysis 81.82% of subjects were correctly classified. Using the logistic regression 72.73% of subjects were correctly classified.

Sensitivity, specificity, positive and negative predictive accuracy and total predictive accuracy was then equal to 82.76, 81.25, 72.73, 82.64 and 81.82 respectively.

a)



b)

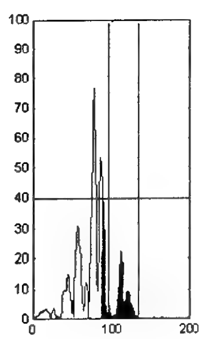
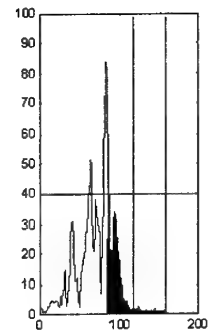


Fig. 1a, 1b: Single beat cardiac micropotentials of healthy subjects classified in Group I, i.e. without presence of late potentials (Fig. 1a) and in Group II, i.e. exhibiting late potentials (Fig. 1b). Scale on the vertical axe is equal to 100 uV, scale on the horizontal axe is equal to 200 msec.
Vertical lines in the image represent end point of the total filtered QRS interval and last 40 msec of the QRS.

a)



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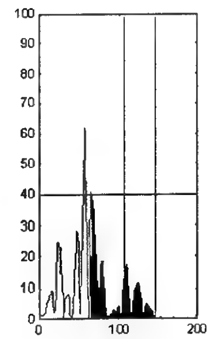

Fig. 2a, 2b: Single beat cardiac micropotentials of two subjects with proved sustained ventricular tachycardia classified in Group II, i.e. exhibiting late potentials.

Table 1: SUMMARY TABLE OF STATISTICS OF PARAMETERS

TQRS = total filtered QRS interval duration
RMS40 = root mean square of last 40 msec of filtered QRS interval
LAS = low amplitude signal at the final part of QRS interval
RMSQ = root mean square of total filtered QRS interval
QRS = duration of QRS interval
Mean1 = mean value in Group I
Mean2 = mean value in Group II
SD1 = Standard Deviation in Group I
SD2 = Standard Deviation in Group II,
T - value = value of unpaired T-test,
Probability = probability level corresponding to the T-value

	Mean1	SD1	Mean2	SD2	T- value	Probability
TQRS	108.44	11.01	132.24	23.12	5.20	<0.001
RMS40	42.29	41.96	34.89	41.85	0.65	0.456
LAS	54.79	13.94	70.52	23.68	3.25	0.002
RMSQ	166.81	74.91	137.28	77.37	1.66	0.102
QRS	96.48	8.58	117.31	20.38	5.23	<0.001

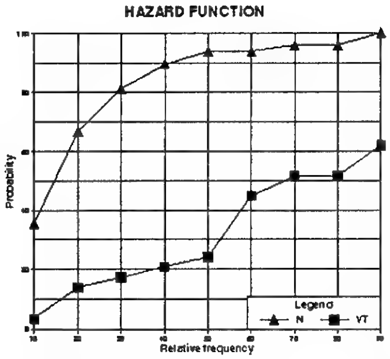

Fig. 3: Hazard function curves derived from logistic regression function by survival analysis for Group I (squares) and Group II (triangles). Probability of developing ventricular tachycardia (18) correspond to the area of chart over the value 50 on the vertical axis.

5. DISCUSION

"Separate peak shape" of the envelop curve of SBLP were frequently observed in the subjects exhibiting the sustained ventricular tachycardia. While this form of LP was found to be significant for discrimination of CAD patients with and without history of ventricular tachycardia, it was found to be non significant for classification under study.

18.75% of healthy subjects being classified into the group of subjects with sustained ventricular tachycardia, i.e. subjects exhibiting LP thus can be kept as subjects with augmented risk of ventricular arrhythmias (i.e. found hazard function over the value of 50) and/or sudden cardiac death.

The significance of presented procedure of LP extraction can be stated:

1. in the relation to the risk of sudden death, for example sudden death described within the normal subjects and within the sportsmen (3, 4, 5, 6, 7, 11, 12, 13).

2. in relation to right ventricular hypertrophy observed in pilots of supersonic aircrafts (1, 15).

3. as one of pathophysiological bases of possible human factors failure in conditions of high professional requirements.

It was proved using the principal components expansion (14) that ECGs from body surface can be reconstructed with sufficient accuracy using 15 orthogonal components. It can be demonstrated for the higher frequency compartments of ECG signal as are LP that even this set of components can be insufficient. Therefore, first twenty singular value decomposition components were adopted for final signal reconstruction.

On the basis of demonstrated results SBLP can be accepted as a suitable part of the set of methods for the early diagnostics of health risks of long-lasting influences of psychosocial stressors. This is valid especially in subjects in highly demanding professions (as pilots and air-traffic controllers).

6. ACKNOWLEDGEMENTS

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ANAEROBIC CAPACITY AND HEIGHT

RELATIONSHIP TO SIMULATED AIR COMBAT MANEUVER (SACM) - DURATION

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ABSTRACT

A method to measure a pilots anaerobic capacity, correlated for height transfer this to an arbitrary measure for "G duration tolerance" (GDT) is described.

Results from 10 subjects form The Armstrong Laboratory, shows a significant correlation between GDT° and SACM duration (P = 0.03).

The method could be an inexpensive tool to get a picture af pilots SACM duration tolerance.

INTRODUCTION

It is a well kown fact that pilots of high performance aircraft (HPA) must perform a coordinated muscletensing effort, know was the Anti-G Straining Maneuver (AGSM), to tolerate high accelerated (G) forces. This voluntary maneuver is very physically demanding and directly related to the ability of the pilot to perform the Anti-G aspects of the Aerial Combat Maneuver (ACM) . (10).

Physical training, resulting in an increased capacity of the cardiovascular system and in an enhanced non-oxidative metabolic capacity of the exercising muscles is one method of improving G-tolerance. (10,13).

The accelerative intertial force (+Gz) of the environment of The ACM of HPA has 2 dimensions that determine human tolerances:

a) G-level

b) G-duration

Typically G-level tolerances are measured using lightloos criteria, such af Grayout or Blackout or using G-induced loss of consciosness (G-LOC), whereas G-duration physiological limitation is a function of pilot fatique. (5).

In this study I am concerned with G-duration tolerance. It is suggested that the limiting factor for enduring sustained high-G is muscular strenght, for the most part anaerobic capacity (6), caused by the special vasculary and cardiopulmonary function under the high-G environment.

In this study I hypothesize a direct relationship between anaerobic capacity, height and Simulated Air Combat Maneuver (SACM) duration (SEC) (4.5-7.0 + Gz, 15 sec.)

HYPOTHESIS

$$\text{G-duration tolerance} = \frac{\text{Wingate Performance}}{\text{H (Meter)}}$$

G-duration tolerance = Arbitrary estimate for ability to endure sustained G-forces.

Wingate Performance = Mean 5 sec. power output during The Wingate Test
(30 sec.,brakeweight = bodyweight x 7,5%)

H: = height (Meter).

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I also found this mathematical model to match the physiology phenomena important for G-duration tolerance.

A wealth of other factors are important for the G-duration tolerance, i.e. psychic condition, straining technique, adequate G - suit protection, ATAGS, Combat Edge Equipment.

Another way to estimate G-duration tolerance using Wingate Performance and height in the formula, is the angle of the pilots position in the diagram determined form (0,0).

G-duration tolerance° =

$$\mathrm{Tan}^{-1} \times K \times \frac{\text{Wingate Performance (W)}}{\text{H (Meter)}}$$

K = 0.0033

I then used data form The Crew Technology Division, Armstrong Laboratory Database, Brooks AFB, TX., including Wingate performance, height and SACM duration (sec) (4.5-7+ Gz).

The subjects were using standard G suit.

SUBJECT	MEANPOWER (W)	H (M)	SACM (SEC)	GDT	GDT°
DC	425	1,73	244	0,82	39°
DB	457	1,74	103	0,87	41°
JR	833	1,96	420	1,42	55°
RS	645	1,71	321	1,26	52°
DL	658	1,80	188	1,22	51°
GM	612	1,80	263	1,13	48°
DAB	613	1,80	229	1,14	49°
LB	768	1,82	369	1,41	55°
JJ	677	1,78	211	1,27	52°
FS	515	1,68	158	1,02	46°

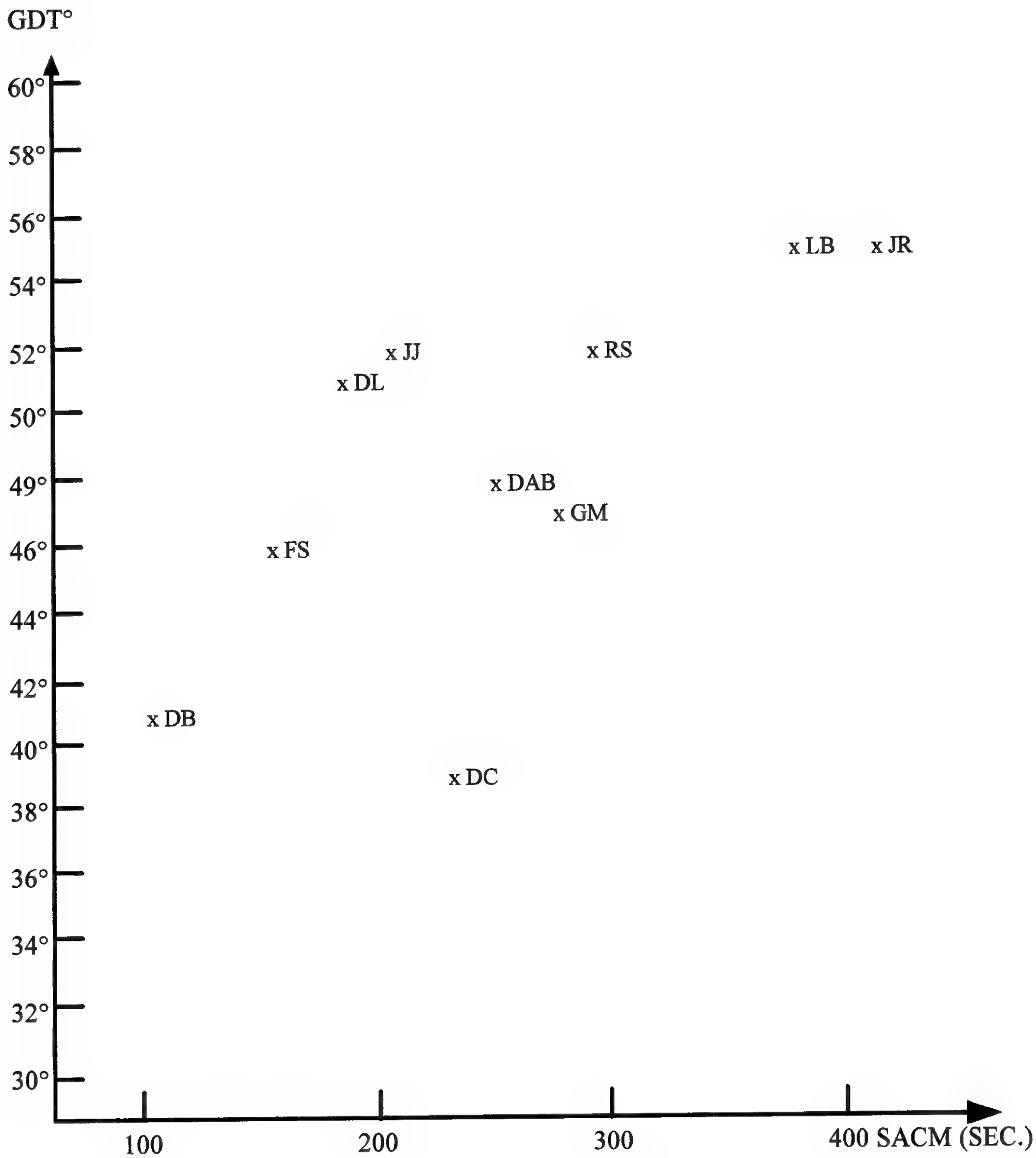
Correlational analysis (Pearson) using 2 viariables,
1) SACM duration (sec.) and 2) GDT°.
N = 10.

Resulting in the following:

$R = 0.68$, $P = 0{,}03$ $R^2 = 0.46$.

This shows a statistically significant ($P \leq 0{,}05$) correlation between SACM duration (sec.) and GDT°.

R^2 is the correlation of determination, indication that 46 % of the SACM duration of these subjects is determined by the calculated GDT°.


GDT°
60°
58°
56°
54°
52°
50°
49°
46°
44°
42°
40°
38°
36°
34°
32°
30°
x LB
x JR
x JJ
x RS
x DL
x DAB
x GM
x FS
x DB
x DC
100
200
300
400 SACM (SEC.)

DISCUSSION

To calculate the GDT° of each pilot I used the mean power output during The Wingate Test Divided by the height of each pilot and transformed this value to degrees ussing the inverse tangent.

The GDT° meansurement cannot be used to predict the SACM duration of an individual pilot on any given day because so many other factors are important in SACM duration,: However, one can conclude that a pilot whit a "good GDT° can endure time in the SACM environment longer than a pilot whit a "poor" GDT° if all other factors are equal.

CONCLUSION

The study shows a direct significant relationship between anerobic capacity correlated for height (Measured as GDT°) and SACM duration. The Wingate Test, used in this way, is an inexpensive and simple way to obtain an estimate of the physical ability of a pilot, to endure sustained G-forces.

The test states nothing about the straining technique of the pilot, his motivation ect.. It is absolutely necessary to continue training pilots in the centrifuge and the flight of HPA.

I recommend that more subjects are evaluated using the GDT° and SACM duration relationship to confirm these findings.

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THE USAF'S ENHANCED FLIGHT SCREENING PROGRAM: PSYCHOLOGICAL ASSESSMENT OF UNDERGRADUATE PILOT TRAINING CANDIDATES

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SUMMARY

The Enhanced Flight Screening (EFS) program consists of both flying and medical screening. This paper will focus on the psychological assessment techniques of the EFS program. Measures of intelligence and cognitive abilities are included. Undergraduate Pilot Training candidates are required to take the Multidimensional Aptitude Battery, an intelligence test, and the CogScreen-Aeromedical Edition, a measure of cognitive skills. Over 1,500 candidates have completed the EFS program. Ninety-four percent of the candidates have consented to allow their data to be used for research. Intelligence testing scores are well above average. Pilot candidates differed from commercial pilots on several cognitive measures. Commercial pilots were more accurate on measures of math abilities, while pilot candidates were more accurate on measures of memory. Commercial pilots were more efficient with most cognitive tasks, except that pilot candidates were more efficient with dual and divided tasks. Commercial pilots made more perseverative errors, while pilot candidates made more impulsive errors. Computer administration of psychological tests makes it possible to efficiently collect clinically relevant data on all candidates. Collection of this data for each candidate will improve the quality of medical waiver recommendations through the use of idiographic data. Collectively, this process provides an infrastructure for productive longitudinal selection research.

INTRODUCTION

Medical evaluation and psychological testing have been part of the military aviator selection process since World War I. The focus of psychological testing has been on identifying factors which predict successful completion of training, typically with measures of general cognitive abilities and, to a lesser extent, measures of personality. Hunter and Burke provide an excellent description of the history of successes and failures of psychological testing in their book on pilot selection (6). Despite the extensive body of research in this area, the integration of psychological data into medical screening has been less than optimal. For example, both the Air Force Officer Qualification Test (AFOQT) and the Basic Attributes Test (BAT) have been found to predict important outcome measures (12, 2). However, the results from the AFOQT and the BAT have limited clinical utility and typically are not included in aeromedical decision making (8).

In an effort to improve the medical screening of pilots, a battery of clinically relevant psychological tests was incorporated into the (EFS) program (1, 10). The EFS program centers around a new training syllabus for the new T-3A "Firefly." The medical component of the EFS program consists of state-of-the-art techniques from ophthalmology and cardiology, as well as psychology. This paper will describe two studies involving the intelligence and cognitive tests.

METHODS

The psychological portion of the EFS program consists of measures of intelligence, cognitive abilities and personality characteristics. The Multidimensional Aptitude Battery (MAB) is a measure of intelligence which consists of five verbal and five performance subtests. The MAB yields Verbal, Performance, and Full Scale Intelligent Quotient (IQ) scores as well as ten subscale scores (7). Correlations between MAB summary scores and Weschler Adult Intelligence Scale - Revised (WAIS-R) scores range from .91 to .98 (7). The CogScreen-Aeromedical Edition (CogScreen-AE) was developed for the medical recertification of civilian aviators by Gary G. Kay, Ph.D. in conjunction with the Federal Aviation Administration (9). It consists of thirteen subtests which measure a wide range of cognitive abilities thought to be critical to the aviation environment, such as attention, memory, visuo-spatial skills and reasoning. Speed and accuracy are scored as well as "thruput," which is a function of both speed and accuracy. The CogScreen-AE has been shown to be useful in identifying brain pathology in aviators (5).

US Air Force (USAF) pilot candidates must complete the EFS program before entering Undergraduate Pilot Training .

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Air Force Academy Cadets complete EFS at the Air Force Academy; all others complete EFS at Hondo, Texas. Pilot candidates are currently required to take the MAB and CogScreen-AE. All tests in the battery are administered via computer. Over 1500 candidates have completed the EFS program, and 94 percent have consented to allow their data to be used for research.

The results in the paper come from two sets of data analysis. First, the computerized version of the MAB was compared with the paper and pencil version in order to determine form equivalence. For this study, the scores of 135 pilot candidates who took the paper-and-pencil version were compared with the scores of 402 pilot candidates who took the computerized version. Second, the CogScreen-AE scores of a sample of 512 pilot candidates were compared with commercial pilot norms derived from the test manual (9). This was done to map cognitive differences across the two samples.

RESULTS

Multidimensional Aptitude Battery

The mean Full Scale IQ for the candidates who took the paper-and-pencil version was 120 and the mean for the candidates taking the computer version was 119. This is not a significant difference (t=1.35, df=535, p=.1761). Further, no significant differences between groups were found on the Verbal IQ's or Performance IQ's.

No differences between means were found for any of the Verbal subtests. No differences between means were found for Picture Completion, Spatial or Object Assembly subtests. Differences between means were found for Digit Symbol and Picture Arrangement. Scores from the computer version of Digit Symbol were slightly higher (29.6 versus 28.1), while scores from the computer version of Picture Arrangement where slightly lower than the paper-and-pencil version (12.3 versus 13.8).

The internal consistency of the Full Scale IQ scores was calculated through Cronbach alpha for both the paper-and-pencil and computer versions of the pilot candidate samples. The paper-and-pencil version was 0.70 and the computer version was 0.80. These statistics are lower than the internal consistencies presented by the test manual for the construction samples, which were 0.96 to 0.98. This is most likely due to the lower number of subjects and the restricted range of scores from the pilot candidate sample.

Plots of the distributions of Full Scale IQ scores suggest that the scores are normally distributed, appear to have similar variance, and do not appear to be skewed or kurtotic.

TABLE 1
Means, standard deviations and t-tests for MAB variables.

Variable	Paper		Computer			
	Means	SD	Means	SD	t	p
Full Scale	120.1	(6.6)	119.1	(7.1)	1.35	.1761
Verbal	118.5	(6.9)	117.9	(7.1)	0.90	.3697
Performance	119.0	(8.3)	117.7	(8.9)	1.48	.1400
Information	29.8	(4.0)	29.3	(4.7)	1.10	.2696
Comprehension	23.3	(2.1)	23.4	(2.2)	-0.26	.7934
Arithmetic	15.7	(2.2)	15.6	(2.0)	0.37	.7142
Similarities	27.6	(3.0)	27.8	(3.0)	-0.63	.5289
Vocabulary	28.8	(5.5)	29.3	(5.8)	-0.74	.4607
Digit Symbol	28.1	(3.6)	29.6	(3.2)	-4.74	.0001*
Picture Completion	26.9	(3.7)	26.9	(3.7)	0.02	.9826
Spatial	37.4	(6.3)	36.6	(6.9)	1.09	.2765
Picture Arrangement	13.8	(2.0)	12.3	(2.0)	7.81	.0001*
Object Assembly	15.9	(3.2)	15.7	(3.1)	0.51	.6129

Note: Summary IQ scores are in scaled score units. Subtest data is in raw score units. * denotes significant differences. SD represents standard deviations.

CogScreen-AE

With 65 variables, the CogScreen-AE is somewhat difficult to present within limited space. Therefore, only representative data will be presented. Data will be presented not by subtest but by type of score. As such, speed variables are presented first, followed by accuracy, thruput and process variables. Since only means and standard deviations of commercial pilots were available, only t tests could be calculated.

Table 2 provides mean comparisons of CogScreen-AE speed variables. In general, commercial pilots are faster on most single type tasks. These include the Math, Match-to-Sample, Manikin, Auditory Sequence Comparison, Pathfinder, and Shifting Attention Tests. Pilot candidates are faster on dual and divided tasks. They are faster on both the Indicator Alone and Indicator Dual elements of the Divided Attention Test. They are also faster than the commercial pilots on the Previous Number Dual speed element of the Dual Task Test. This result indicates a consistent difference between the two groups with respect to simple, focused versus complex reaction times, with commercial pilots better at the former and pilot candidates better at the latter.

Table 3 provides mean comparisons of CogScreen-AE accuracy variables. Many mean accuracy scores are above 90%. This restriction in range due to ceiling effects results in unstable inferential statistical results. Therefore only variables without this restriction in range will be described.

On the remaining variables, commercial pilots are better at math with 86% of items correctly answered compared to 72% for pilot candidates. Pilot candidates, however, are better at remembering digits backward, coding symbols for digits both immediately and in delayed memory format, and remembering previous numbers while performing the Dual Task Test. Pilot candidates appear to have superior memory across a number of tasks.

Table 4 provides mean comparisons of selected CogScreen-AE thruput and process variables. Thruput is a function of both speed and accuracy. Only the Math Thruput variable is based on an accuracy which had a reasonable amount of variance. Process variables indicate a wide range of test behaviors. There are two variables which appear to differentiate between the groups. Commercial pilots made more perseverative errors suggesting that they continued to respond in a manner which may have been successful in the past but was no longer appropriate. Pilot candidates more often "failed to maintain set" on the attention shifting task meaning that they failed to thoroughly learn a task prior to changing approaches. The two groups differ on this common discipline dimension with commercial pilots perhaps overly disciplined and pilot candidates insufficiently disciplined.

TABLE 2
Means, Standard Deviations and *t*-tests for CogScreen-AE Speed Variables.

Variable	Pilot Candidates		Commercial Pilots		
	Mean	SD	Mean	SD	*t*
MATH	27.25	8.79	20.10	7.58	14.32*
VSC	2.24	.51	2.21	.55	0.94
MTS	1.47	.28	1.32	.24	9.45*
MAN	1.98	.38	1.78	.41	8.38*
DATI	.40	.07	.42	.09	-4.13*
DATD	.69	.20	.76	.23	-5.39*
DATSC	2.15	.53	2.24	.60	-2.64
ASC	.98	.24	.83	.20	11.15*
PFN	.85	.16	.79	.23	5.06*
PFL	.79	.13	.64	.18	15.95*
PFC	1.20	.30	1.09	.36	5.52*
SATAD	.70	.10	.54	.09	27.68*
SATAC	.68	.09	.55	.11	21.51*
SATIN	.86	.15	.75	.15	12.11*
SATDI	.95	.21	.87	.25	5.75*
DTTPA	.48	.19	.51	.24	-2.31
DTTPD	.66	.24	.72	.27	-3.89*
N	512		584		

Note: Please see Appendix A for variable name definitions.
* denotes significance at .001 ($t > 3.29$).

TABLE 3
Means, Standard Deviations and *t*-tests for CogScreen-AE Accuracy Variables.

Variable	Pilot Candidates		Commercial Pilots		
	Means	SD	Means	SD	*t*
BDS	.89	.12	.84	.20	5.09*
MATH	.72	.19	.86	.17	-12.78*
VSC	.97	.03	.98	.03	-5.51*a
SDC	.99	.01	.98	.03	7.59*a
SDCIR	.94	.13	.86	.20	7.94*
SDCDR	.93	.15	.84	.22	7.99*
MTS	.95	.05	.96	.05	-3.30*a
MAN	.93	.09	.92	.10	1.74 a
DATSC	.89	.07	.87	.08	4.41*a
ASC	.90	.10	.93	.08	-5.43*a
PFN	.99	.01	1.00	.01	-16.52*a
PFL	.99	.01	.99	.02	0.00 a
PFC	.98	.03	.98	.04	0.00 a
SATAD	.98	.03	.99	.03	-5.05*a
SATAC	.99	.03	.99	.03	0.00 a
SATIN	.97	.03	.98	.04	-4.72*a
SATDI	.67	.11	.68	.12	-1.44
DTTPA	.93	.07	.91	.11	3.63*
DTTPD	.86	.11	.81	.15	6.34*
N	512		584		

Note: The "a" denotes variables with so little variance due to ceiling effect that the significant *t* statistics are probably unstable and uninterpretable.

* denotes significance at .001 ($t > 3.29$).

DISCUSSION

Computer administration of psychological tests has made it practical to collect clinically relevant data on all pilot candidates before they enter Undergraduate Pilot training. Careful evaluation has shown that there are few differences between MAB scores obtained by pilot candidates taking computer versions versus paper-and-pencil versions. Reliability analysis indicates that both versions are reliable. Interestingly, the computer version is actually more reliable for pilot candidates. The results in this study are remarkably similar to other studies of IQ in USAF student pilots (11) and Air National Guard Pilots (4). These studies suggest that there are few differences between pilots, student pilots and pilot candidates with regard to intelligence. They are well above the population as a whole.

There are differences between pilot candidates and the commercial pilot norms available for the CogScreen-AE.

Commercial pilots were more accurate and more productive in solving arithmetic problems, while pilot candidates were more accurate on measures of numeric working memory. Commercial pilots were more efficient with focused cognitive tasks, while pilot candidates were more efficient with dual and divided tasks. Commercial pilots made more perseverative errors, while pilot candidates made more impulsive errors. It should be noted that these two groups not only differed in respect to actual pilot status but also age. Age differences are highly correlated with cognitive ability. However, while the difference in age may have contributed to the superior performance of the pilot candidates on some measures, pilot candidates performance on some measures was below that of the commercial pilot norms. It is likely that the benefits of age were counteracted by the benefits of selection and experience. The two confounding variables may have balanced each other out. These differences reinforce the need for population specific data since even fully rated USAF pilots are younger than most commercial pilots.

TABLE 4
Means, Standard Deviations and *t*-tests for CogScreen-AE Speed Variables.

Variable	Pilot Candidates		Commercial Pilots		
	Means	SD	Means	SD	*t*
Thruput					
MATH	1.82	1.22	3.00	1.40	-14.91*
SDC	33.74	6.00	33.00	8.20	1.72
SATDI	44.64	11.68	50.20	15.70	-6.70*
DTTPA	131.25	46.15	134.00	84.80	-0.68
DTTPD	90.85	38.48	80.20	45.00	4.22*
Process					
DATIPRE	2.52	1.80	2.70	1.90	-1.61
DATDPRE	2.22	2.04	2.60	2.40	-2.83
SATDIRUL	6.96	2.50	7.30	2.50	-2.25
SATDIFAI	2.15	1.92	1.40	1.80	6.64*
SATDIPER	1.89	2.51	2.80	3.20	-5.27*
SATDINON	1.57	2.71	1.90	3.20	-1.85
DTTAHIT	.92	1.95	1.20	1.90	-2.40
DTTDHIT	3.46	3.39	3.10	3.30	1.92
N	512		584		

Note: * denotes significance at .001 ($t > 3.29$).

Collection of clinically relevant psychological data for each pilot candidate represents a significant step forward in the medical screening of USAF pilots. This data will lead to better clinical assessments in two ways; first, by providing idiographic data for those pilots who have been tested, and second, by providing improved normative data for those pilots who have not been tested. Additionally, the process of evaluating each pilot candidate prior to training provides an infrastructure for productive longitudinal selection, training, and assignment research.

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APPENDIX A
CogScreen Variable Definitions

BDS	Backward Digit Span
MATH	Math
VSC	Visual Sequence Comparison
SDC	Symbol Digit Coding
SDCIR	SDC--Immediate Recall
SDCDR	SDC--Delayed Recall
MTS	Matching to Sample
MAN	Manikin Test
DATI	Divided Attention Test--Indicator Alone
DATD	Divided Attention Test--Indicator Dual
DATIPRE	DATI--Premature Response
DATDPRE	DATD--Premature Response
DATSC	DAT--Sequence Comparison
ASC	Auditory Sequence Comparison
PFN	Pathfinder Number
PFL	Pathfinder Letter
PFC	Pathfinder Combined
SATAD	Shifting Attention Test--Arrow Direction
SATAC	Shifting Attention Test--Arrow Color
SATIN	Shifting Attention Test--Instruction
SATDI	Shifting Attention Test--Discovery
SATDIRUL	SATDI--Rule Shifts Completed
SATDIFAI	SATDI--Failed Set
SATDIPER	SATDI--Perseveration Set
SATDINON	SATDI--Nonconcept Response
DTT	Dual Task Test
DTTPA	DTT--Previous Number Alone
DTTPD	DTT--Previous Number Dual
DTTAHIT	DTT--Tracking Alone Boundary Hits
DTTDHIT	DTT--Tracking Dual Boundary Hits

SIMULATOR BASED TEST SYSTEMS AS A MEASURE TO IMPROVE THE PROGNOSTIC VALUE OF AIRCREW SELECTION

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Summary

A simulator based aviation psychological test system in use in the German Air Force called the 'FPS 80' which is the German abbreviation of 'Aviation Psychological Selection System 80' is described to point out the advantages and the disadvantages of simulator based tests in comparison to classical psychological tests. While classical psychological tests try to examine single abilities simulator based test systems measure a student pilot's abilities in a complex test situation similar to a real training situation. The role of the FPS 80 within the sequential selection strategy of the GAF will be described in the study.

The results of a study based on the data of over 300 student pilots of the years 1994 and 1995 show that the prognostic value of the whole selection system could be increased considerably by using simulator based tests. The prognostic value of the selection process becomes evident in the correlations of psychological data and the results of academic training and of flight training in the flying screening. A comparison of the prognostic value with and without the use of the FPS 80 shows that the correlation of the whole selection process could be increased from .3 to over .5. The results also show that the prognostic value of the FPS 80 itself could be increased by adding data from a psychological observation of behaviour to the computer generated test scores. As a conclusion the advantages and the limits of such a simulator based test system are pointed out.

1. Introduction

In the German Air Force a sequential selection system is used for aircrew selection. It consists of several major steps (figure 1). The first step for a typical applicant who wants to become a pilot in the GAF is to pass the tests at the officer selection center (non commissioned officers go a slightly different way) . There, psychological basic testing of cognitive abilities for flying duties is done.

Thereafter the applicant is sent to the Institute of Aviation Medicine where he undergoes special aviation medical and aviation psychological examinations. With a delay of about two years - having finished college and having successfully attended the Officer School (including Aviation English training) -the FPS 80 phase sets in. Finally he will be sent to the flying screening program where he gets academic training as well as his first flight lessons. Originally the FPS 80 was designed only to provide additional psychologic information for the screening, since - at that time - the FPS 80 phase was part of the screening program. When the screening squadron was moved to the USA, the FPS 80 had to remain in Germany. Thus the FPS 80 phase is the only step in the whole selection process where up to now no candidates can be eliminated. The decision which student will become a pilot or a weapon systems operator is taken, when the student has successfully passed the screening program. Then the student pilots are sent to the various training units.

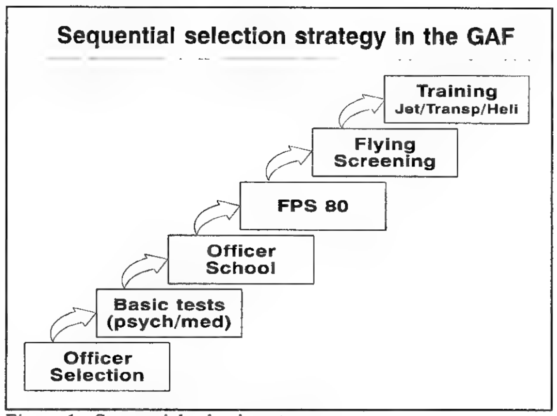

Figure 1 - Sequential selection strategy

2. Description of the system

As shown before, the FPS 80 phase sets in when the candidate has successfully completed Officer School but before the flying screening begins. The concept of the FPS 80 is that of a 'hands on test' to estimate a student pilot's abilities necessary to meet the requirements of a later flight training. In a complex test situation resembling very much a real training situation a student pilot has to fulfill flight specific tasks in several missions. When, in 1990, its validity had been determined, the FPS 80 was put in official use.

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The FPS 80 system itself is a low fidelity simulator consisting of a control center and two cockpits. Each cockpit includes basic controls (stick, rudder, throttle, gear lever, flaps lever, parking brake), basic instruments (thrust indicator, speed indicator, artificial horizon, altimeter, vertical velocity indicator, G-meter, flaps and gear indicator) and a visual system. The visual system with three screens provides limited side view. For monetary reasons no motion system is integrated. The internal flight model used for the computer simulation is a Piaggio 149 D. This single-engine prop plane was used in the GAF for screening purposes until 1989. As most of the candidates at this stage are ´pedestrians´ without experience in flying the flight model used in the simulation is a reduced one (e. g. automatic trimming, no torque effect). This is necessary as you cannot expect to expect too much of the candidates, but on the other hand the workload must be kept high enough to differentiate the students´ abilities.

3. Description of the missions

In the FPS 80 phase each student pilot of a class of 14 has to fly four of the five missions, briefly described in figure 2, within two weeks.

FPS 80	Description of the mission
Mission 1	Taxiing to the runway; take off; three level turns with shallow, medium and steep bank; automatic landing by the computer as a preparation for mission 2
Mission 2	Pattern mission with three complete traffic patterns, each of them with a full stop landing.
Mission 3	Low level navigation mission with weapon systems operator specific tasks (currently not flown due to lack of time).
Mission 4	Traffic pattern; recoveries from unusual attitudes; elements of formation flying; intercept and attack of an enemy aircraft.
Mission 5	Flight through an abstract tunnel.

Figure 2

The missions have to be flown according to standard procedures where the student pilot has to keep the limits given for the flight parameters (speed, altitude, bank angle, climb rate, heading etc.). The sequence of the missions begins with a relatively low workload in mission 1. From mission to mission the workload increases.

An exception to this rule is mission 5, where the student pilot has to react very quickly and well a well coordinated manner to compensate standardized computer generated deviations. In this mission especially senso motor skills rather than cognitive components are checked.

For a good preparation, every student gets a training guide with a detailed description of the missions and the procedures one week before the missions start. As most of the candidates are still completely inexperienced in flying two training lessons with aerodynamic basics were introduced. To ensure that only well prepared student pilots fly the FPS missions a written test is given just before the first mission. If a student fails this test he is not admitted to fly the mission and will be recoursed.

The sequence in each mission is comparable to the sequence in a real training situation:

- Demonstration
- Practice
- Able to perform

Before a student enters the cockpit he gets a mission briefing by an experienced instructor pilot. In this briefing all important steps of the mission are explained. After that the student pilot climbs into the cockpit to receive a computer controlled standardized demonstration of the mission. Then the student practises the procedures as learned before with the assistance of the instructor pilot. Any mistakes occurring will be debriefed. Finally the student pilot has to fly the check phase without any help. After the mission he will be debriefed on his performance.

If a student exceeds the given limits for a manoeuvre the aircraft will be repositioned and the student pilot will get the opportunity to repeat this manoeuvre (Maximum: three times). This is necessary to determine whether the reason for a failure is based - for example - on a lack of concentration or on missing other abilities.

During the check phase the computer will save the data of the flight. The student is graded in the check phase by two ways:

- Computer generated test scores based on the data saved during the check phase.
- A semi standardized observation of behaviour by an aviation psychologist.

In order to calculate test scores based on the data of the flight, each mission is split up into separate phases (e.g. take off, climb phase, turn etc.). This is necessary because mission tasks differ from phase to phase (for example a speed deviation on a leg is not comparable to a speed deviation in the final approach). Algorithms comparable to those usually used for multidimensional tracking experiments were developed for each phase of a mission. Thus computer scores for each phase are calculated. These scores are influenced by the weighted deviations from the ideal track as well as the weighted inputs of the student pilot. The weighted scores of the

phases are used to generate an overall computer test score for a mission. The weights of the parameters of a phase as well as the weights of the phases scores have been obtained by a statistical analysis in 1990.

During the observation of behaviour the following psychological variables are graded on a scale from '1' to '5':

- Receptiveness
- Stress resistance
- Training progress (compared to the practice phase)
- Aggressiveness
- Constancy of performance
- Concentration
- Coordination
- Micro motor coordination
- Precision
- Distribution of attention
- Multi tasking
- Sensomotor skills.

The scale used was defined in statistical terms with a mean of 3 and standard deviation of 1. The meaning of the several grades is explained in figure 3.

Grade in FPS 80	**Meaning**
'1'	Excellent performance or abilities with a very good chance to become a pilot
'2'	Above average performance with an above average chance to become a pilot
'3'	Average performance with average chance to become a pilot
'4'	Fair performance with a below average chance to become a pilot
'5'	Unsatisfactory performance with a marginal chance to become a pilot

Figure 3

For each mission an overall grade is computed by combining the computer scores and the grades based on the observation of behaviour. To summarize the performance for the whole FPS 80 phase a total grade is generated from all mission scores. All these results are sent to the screening squadron. There they contribute to the decision of the training review board.

4. Results

Figure 4 shows the outcome of the latest correlation analysis to estimate the prognostic value of the psychological selection. In this study the academic scores and the flying scores obtained in the screening program were used as criteria. The basic sample used for this study consists of the data of 331 student pilots that went through the screening program in the course of the last two years. Due to drop outs during the academic phase of the screening the number of student pilots finishing academics decreases to 310. The number of student pilots who finished flight training and obtained a flying score further decreases to 267 by attritions after the academic phase. All correlation coefficients shown are highly significant.

	Correlations with	
Predictors	Academic Score N=310	Flying Score N=267
Aviation psychological basic tests	-.24	-.30
FPS 80 computer grade	-.38	-.44
FPS 80 Grade incl. observation of behaviour	-.41	-.52
FPS 80 grade combined with basic tests	-.42	-.54

Figure 4

To describe the prognostic value of the psychological basic examination the final grades of this selection step are used as a predictor. These grades range from '1' to '4' where '1' means good abilities with high probability to succeed in flight training. Increasing grades represent decreasing quality of abilities with reduced probability to succeed.

A comparison of the correlations between the results in the psychological basic examination and the outcome in the screening with the correlations of the FPS 80 computer grades and screening results shows that the use of the FPS 80 computer scores alone makes up for significantly better predictions. While the correlation between the psychological basic tests and academics is about -.24 the correlation of the FPS 80 with academics is -.38. Also with regard to the results in the flying screening program the data show that the FPS 80 - with a correlation coefficient of -.44 - allows a better prediction than the data of the basic tests - with a correlation coefficient of -.30.

By combining the FPS 80 computer grades with the grades obtained by observation of behaviour the correlation with academics increases to -.41 and the correlations with the flying screening scores increases to -.52.

A combination of the results of the basic tests and the total FPS 80 grades in a fictive overall score for aviation psychological diagnostics would increase the correlation with academics to -.42. The correlation with the flying screening program would increase to -.54. But as the differences between the correlations of the FPS 80 grades

and the combined score are rather small, these differences are not significant. They only reflect a trend. The main reason for those small differences is a high degree of redundancy as most of the variables checked in the basic examination have to be checked in the FPS 80 too (but not vice versa).

The high prognostic value of the FPS 80 is also remarkable because the sample going through the FPS 80 is a preselected part of the population with reduced variance (due to the preceding selection steps). This also means that the true correlation of the FPS 80 in a not preselected population certainly would be substantially higher.

As highly significant correlations are not necessarily meaningful for a selection process (e.g. a correlation coefficient of .05 would be significant if the data sample is large enough but useless for selection because the selection rate would be too high) the predictive value of the FPS 80 is illustrated by showing the portions of potential future jet pilots after the screening phase with respect to the grade received in the FPS 80 (figure 5).
As there is a minimum flying screening score of 70 points required in the German Air Force to enter the jet pilot training this criterion is used to describe the quantitative output of potential jet pilots after screening.

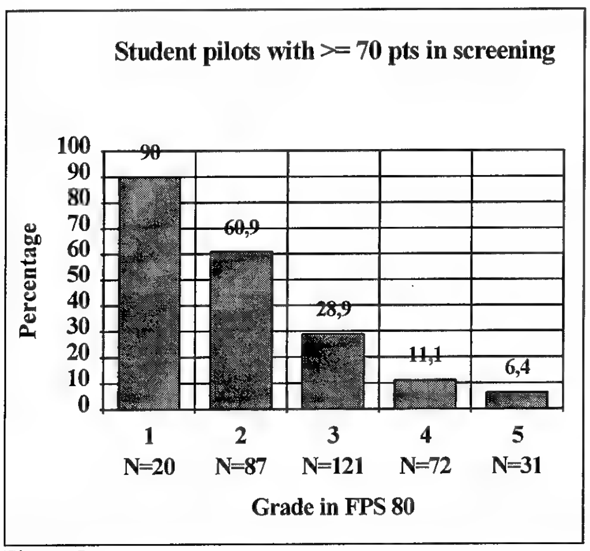

Figure 5

While 90% of those graded with '1' in the FPS 80 meet this requirement the portion of student pilots who fulfill this criterion decreases rapidly with decreasing performance in the FPS 80. There is a 6.4% chance of a student pilot graded with '5' in the FPS 80 to achieve 70 or more points in the flying screening program.
This means: In order to find a single student pilot who meets the requirements to enter the jet pilot training 15 applicants of this group would have to be sent into the flying screening program. In economic terms it makes little sense to send this group into the screening. This becomes evident if we consider the fact that almost half of the very few candidates failed in the jet pilot training although they achieved over 70 points in flying screening despite a grade of '5' obtained in the FPS.

If the FPS 80 were used for a selection of the better ones, and if for example only applicants with a grade of '1' and '2' were accepted, the portion of such candidates who meet the criterion to enter jet pilot training after flying screening would increase from 35 percent (for the total sample) to about 66 percent.

The prognostic value of the FPS 80 also impressed the military leaders responsible for selection and training so that a decision is in preparation to make the FPS 80 phase a selection step of its own.

5. Conclusions

Simulator based psychological test systems as shown on the example of the FPS 80 have proved to be a valuable part in a selection system. They allow a much more precise diagnosis of student pilots' abilities than classical psychological tests do. The main advantage of such a simulator based test is the possibility to examine abilities in a very complex situation on the ground which so far could only be checked in an airplane. Apart from a high prognostic value, simulator based tests involve much less costs than flight lessons. A further advantage of such a system over a screening program is its higher degree of standardization which is achieved by using computer controlled missions.

While most classical psychological tests try to estimate a single ability or a limited set of abilities, simulator based tests allow to check a larger set of an applicant's abilities including their interactive effects in a complex situation. A further advantage of systems like the FPS 80 is that the obtained findings do not only give a spotlight impression of an applicant's performance on a single day as several points of measurement are taken over a longer period. But this is also the greatest disadvantage of such a simulator based test system: it is more expensive than classical psychological tests. For this reason simulator based test systems like the FPS 80 will not be applicable for basic testing of all applicants without introducing changes. In order to use the advantages of simulator based tests in a basic examination such a system will have to be modified to fit in the given time. Unfortunately this probably will lead to a loss of information and thus influence its predictive value.

Although a test system like the FPS 80 comes very close to a real training situation it will not be able to replace the flying screening completely, as there are factors in an airplane - like the real third dimension - which cannot be simulated on the ground.

SELECTION OF SPECIAL DUTY AVIATORS: COGNITIVE AND PERSONALITY FINDINGS

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INTRODUCTION

This paper will describe a selection program for special duty aviators. Different from other selection programs, this program selects already trained pilots as well as other non trained crewmembers such as loadmasters and flight engineers for special aviation duty. These aviators are selected to fly for the U.S. Air Force Special Operations Command (AFSOC) in airframes such as the MH 53 helicopter.

BACKGROUND

In May 1990 U.S. Air Force (USAF) special operations were organized under a new commander who believed that their missions required select and motivated personnel, due to the demands of crew coordination and night operations. As the Command stated the problem: 1. training failures were expensive; 2. some could complete training but never become mission ready; 3. some individuals were never trusted operationally; 4. and, in summary, as with many aviation missions, their missions allowed for no errors and yet had very high operations tempo.

The Commander asked us to rapidly develop a screening and orientation program to begin to answer these problems. We chose a clinical/research approach that utilized the many years of experience at the USAF Aeromedical Consultation Service evaluating aviators and National Aeronautics and Space Administration (NASA) astronauts to quickly build a research-based program for evaluation that would change and improve as data became available.

METHODS

We began the project by interviewing current unit members, which helped further define the problem and psychological requirements and we investigated other selection programs. We then baselined the current unit members with selected psychological instruments; current unit members were viewed as relatively representative of what it takes to do these missions successfully.

We began the first selection about 8 months after our first contact with the Commander and we have conducted 28 one-week cycles, screening 345 applicants. All applicant's personnel folders are prescreened. We update the program as needed based on applicant, unit and data feedback.

The program is a select-out as well as a select-in or suitability program. We use the Multidimensional Aptitude Battery (MAB) for cognitive testing as both a select-in and select-out measure. That is, a minimum score based on 1sd below the baseline mean is required (select-out threshold) but a higher score is preferred (select-in). We also use the NEO Personality Inventory (a five factor self report test) and an interview for select-in characteristics such as interpersonal strengths, discipline and motivation. We use the Minnesota Multiphasic Personality Inventory (MMPI) and the interview to screen for psychopathology and family problems (select-out). Psychologists interpret the tests and conduct interviews and then make suitability recommendations to the operational commanders for final decision. Psychologist ratings are either: exceptionally well qualified (EWQ), qualified (Q), qualified with reservations (Qr), or disqualified (DQ). A board of operational commanders conduct independent interviews and make final hiring decisions of either: select (S), or reject (R). Applicants who are selected are allowed to decline (D).

Future plans include multivariate analysis but the current sample available for analysis is still too small given the number of variables. Thus, for this paper, we will report on the following research questions:
1. Are there differences between baseline unit members and applicants?
2. Are there differences between applicants to different crew positions? (We speculated that answers to this question might have implications for cockpit resource management.
3. Are there applicant differences among applicants according to the board decisions and psychologists recommendations?
4. Are there differences between psychologist's ratings and board decisions?

SAMPLE DESCRIPTION

	Baseline	Applicant
Pilots	42	86
Flight Engineers (FE)	31	56
Other (loadmaster, gunners)	58	72
Total	131	214

Fig 1. Sample Description

Paper presented at the AMP Symposium on "Selection and Training Advances in Aviation", held in Prague, Czech Republic, in May 1996, and published in CP-588.

The sample includes 131 baselined unit members and 214 applicants (Figure 1). We will report on 3 crew positions: Pilot, Flight Engineer and Other aircrew such as loadmasters and gunners. All Pilot applicants are officers, are trained pilots and have completed university training. All Flight Engineers (FEs) and Other crewmembers are enlisted and may have some college training; most are not trained in flying jobs but have mechanical or technical training. Figure 2 shows that the baselined group is older than the applicants. Figure 3 indicates that most applicants are married which has implications for commanders and personnel management (marital information was not collected on baseline members).

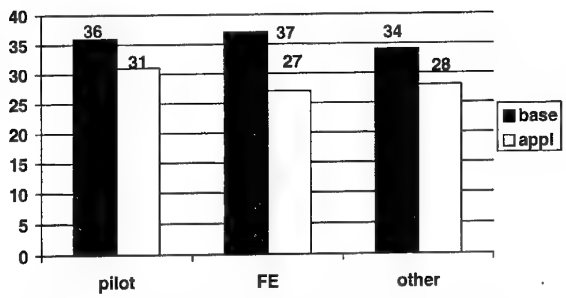


Fig 2. Mean ages of baseline and applicants by crew position

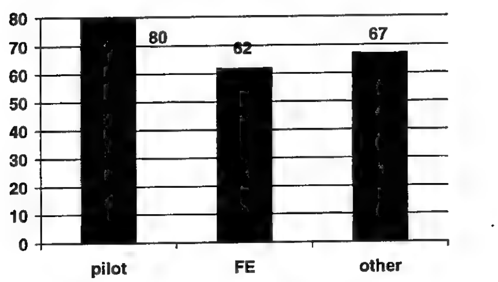
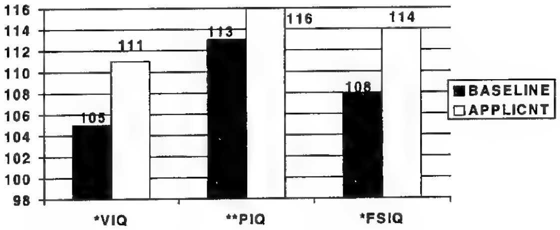


Fig 3. % applicants married by crew position

FINDINGS

Question 1 (baseline applicant differences):

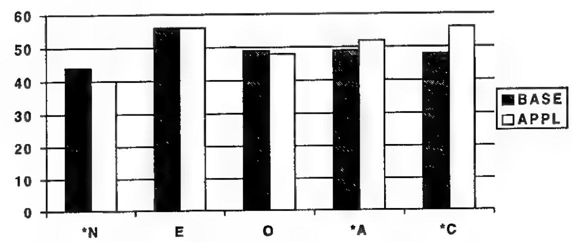
Figure 4 shows a statistical difference in cognitive ability between baselined unit members and applicants with the applicants being superior to current unit members.



t-test *p < .001 **p = .07

Fig 4. Comparison of baseline and applicant MAB means

Figure 5 indicates that applicants differ from baseline members in that applicants admit to less psychopathology (N), and indicate they are more Agreeable (A) and more Conscientious (C). Others have noted a "honeymoon" effect for job applicants such that applicants present themselves very favorably; this may be the case here. Conversely, however, there were no differences found on Extroversion (E) or Openness (O).



t-test *p < .05

Fig 5. Comparison of baseline and applicant NEO domain means

Question 2 (crew position differences):

We did not use statistical tests here, but Figure 6 suggests that our college educated Pilot applicants perform better on verbal (VIQ), performance (PIQ), and combined (FSIQ) cognitive scores than FEs or Others. Interestingly, the FE position is seen as the most demanding and those applicants score slightly lower than the Other aircrew applicants.

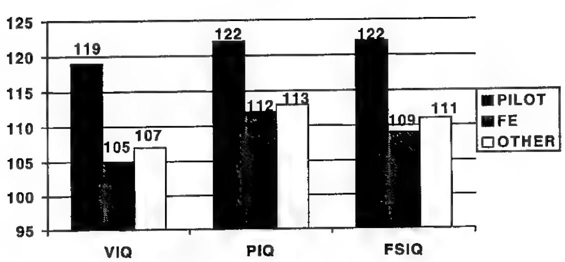


Fig 6. Applicant MAB mean score by crew position

Neither do we report statistical testing on the personality differences, but Figure 7 indicates that Pilot applicants admit to less psychopathology, and are more extroverted, open, agreeable and more conscientious. Again FE applicants admit to more psychopathology, and are slightly more agreeable and less open than Other enlisted crew applicants.

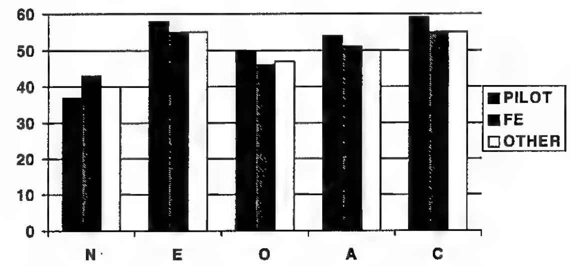


Fig 7. Applicant NEO domain score by crew position

Pilots were most highly rated by psychologists, while FEs were lowest rated (Figure 8). This finding may indicate psychologists' recognition that the FE job is the most demanding, resulting in the psychologists using a higher critical threshold for FE applicants.

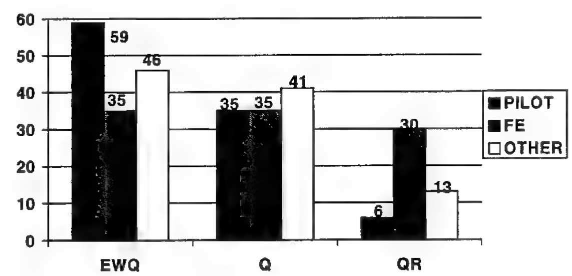


Fig 8. Psychologist rating (%) of applicants by crew position

Different from the psychologists, the Board decision favored FEs and Other aircrew applicants and rejected more Pilots (Figure 9). Interestingly, more Pilots declined than other applicants.

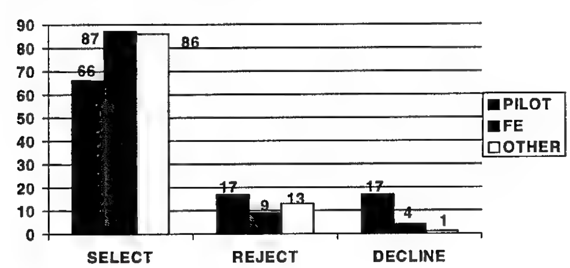


Fig 9. Board decision (%) of applicants by crew position

Question 3 (contributions to psychologist ratings) :

Looking further at the differences among the applicants, using analysis of variance (ANOVA), we asked what applicants seemed to get which psychologist ratings. The better the cognitive scores, the better the psychologist ratings (Figure 10), suggesting that the psychologists recognize the importance of cognition for these missions or suggesting that applicants with better cognitive scores more favorably impress the interviewers.

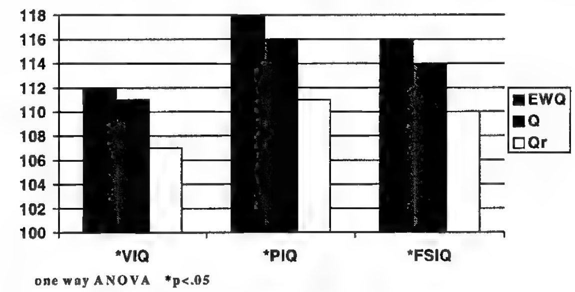


Fig 10. Comparison of MAB by psychologists ratings

As noted before, scores on Neuroticism (N), Agreeableness (A) and Conscientiousness (C) produced significant differences in psychologist ratings while differences were not found for Extroversion (E) or Openness (O) (Figure 11). The best rated applicants admitted to less psychopathology, and were more agreeable and rated themselves highly conscientious. Though not statistically significant, the better rated applicants were more extroverted and more open.

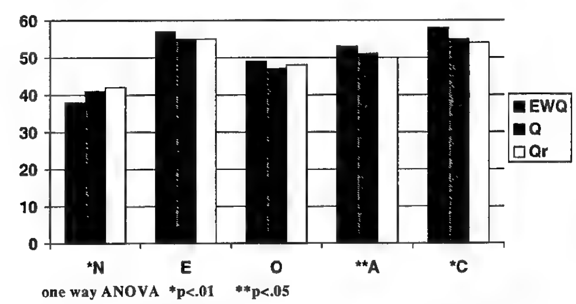
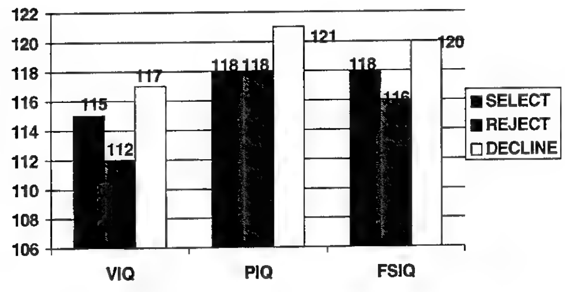


Fig 11. Comparison of NEO scores by psychologists ratings

Question 4 (Board decision influences) :

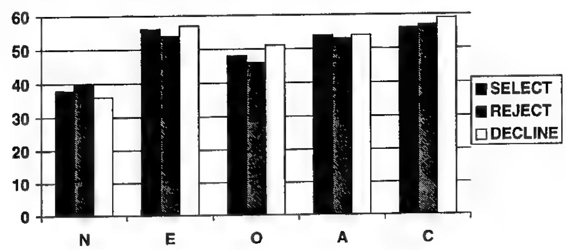
We also compared the measured psychological characteristics with the board decisions. No statistical differences were found for cognitive differences when compared with the board decision (Figure 12). However, a trend to observe and further investigate is that the applicants who Decline have high cognitive scores! Are these applicants saying, "I may be crazy but I'm not stupid?"



one way ANOVA p>.05

Fig 12. Comparison of MAB by board decision

Similarly, no statistical differences were found when comparing personality data with board decisions (Figure 13). As would be hoped, the trends suggest that those higher on Neuroticism, less Extroversion, Openness, and Agreeableness are more often Rejected; again those who Decline often have positive and perhaps desirable personality characteristics.



one way ANOVA p>.05 (0.86)

Fig 13. Comparison of NEO by board decision

Question 5 (rater reliability compared with board decision):

Finally, we evaluated aspects of how the psychologists ratings and board decisions are related. Figure 14 shows the effects of prescreening. About 80% of the applicants were rated acceptable by the psychologists. Similar to other selection programs we studied, 14% of the applicants were found to be of questionable suitability, and only 2 of the applicants were disqualified. The DQs were based upon personality/interpersonal findings and family problems.

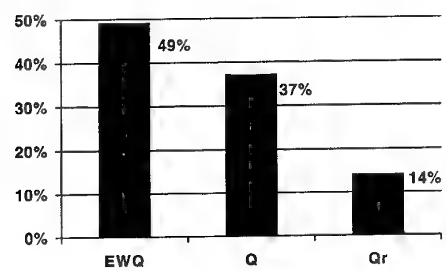


Fig 14. Overall psychologist ratings

The Boards were slightly more discriminating, selecting only 76% (Figure 15). Again 16% declined the job offer.

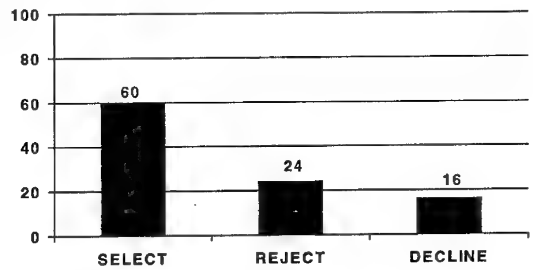
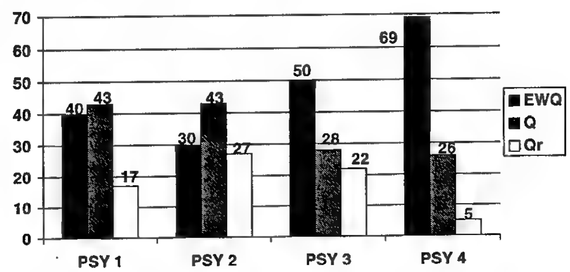


Fig 15. Overall board decision

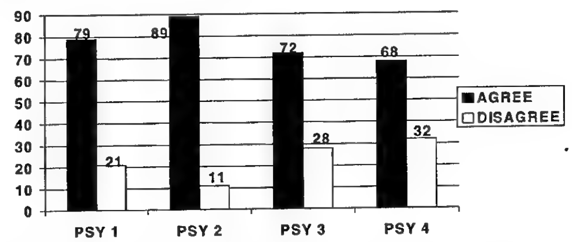
We now have 8 trained evaluators who assist with the project. Evaluees are randomly assigned to evaluators, though some evaluators have more clinical as well as selection experience than others. Figure 16 shows that there is variability between the 4 psychologists who have done most of the assessments. It appears that psychologists 3 and 4 respond more to the "honeymoon effect" than 1 and 2.



chi-square p<.01

Fig 16. Comparisons between % of evaluator's ratings

Despite the statistical differences between the psychologists, there is no difference between the various psychologists' agreement with the board decision, though the trend indicates that psychologist 1 and 2 agree more often than 3 and especially 4 (Figure 17).



chi-sq p>.05 (0.63)

Fig 17. % overall agreement between evaluators and board

CONCLUSIONS

Thus, we conclude that:

Question 1 (baseline, applicant differences)
-Applicants are cognitively superior to baseline unit members
-Applicants admit to less psychopathology than baseline unit members
-Applicants are more agreeable and conscientious
-Applicants appear to be superior to baseline unit members

Question 2 (crew position differences)
-Pilot applicants are cognitively superior to other aircrew applicants who may be slightly superior to FE applicants
-Pilots admit to slightly less psychopathology (FEs slightly more) and are slightly more extroverted, open, agreeable and conscientious than FEs or Other aircrew
-Pilots are rated more highly than Other aircrew who are higher than FEs (30% Qr)
-Pilots are more often Rejected by board decision and more often Decline than either FE or Other aircrew (different from psychologist ratings)
-Psychologists appear to be most concerned about FEs while Board members may be most concerned about Pilots

Question 3 (contributions to psychologist ratings)
-Cognitive test results appear to influence ratings of applicants particularly among pilots and FEs; the opposite may be true for Other aircrew
-Higher psychologist ratings are associated with lower Neuroticism, and higher Agreeableness and Conscientiousness, but not Extroversion nor Openness
-Pilots who are much higher on Extroversion and Openness are rated lower
-Prescreening provides excellent candidates (49% EWQ)
-Qr rate (14%) comparable to other special duty selection

Question 4 (Board decision influences)
-Board decisions may be preferential to higher applicant cognitive scores (but not statistically)
-Those who decline have the highest cognitive scores (small n)
-Board decisions do not appear to be related to personality findings; visual inspection indicates expected trends

Question 5 (rater reliability with board decision)
-There are differences between psychologists, but overall psychologist ratings do not differ with the board decisions

FUTURE DIRECTIONS

We will continue program evaluation developing a larger data base (about 200 applicants per year) in order to use multivariate methods such as logistic regression. For further program evaluation we will also begin outcome assessments. We will use supervisor ratings of the new unit members which will be based upon the same variables used by the psychologists.

We are ready to specifically evaluate our psychometric instruments to see if they are efficient selection tools; as the project is a testbed we will add or delete components as indicated. We are developing a new interview for the board at this time, as the old interview has been judged to be too redundant with the psychological interview.

We hope to extend the program to new units. This past spring (1996) we began a new selection program with a fixed wing unit and this summer we will begin developing a program for a fighter jet unit.

The authors wish to recognize and thank Ms Julie Yochum for her support in preparing this paper.

R&D ADVANCES IN USAF PILOT TRAINING

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SUMMARY

Recent advances in aircrew training methods and technologies now allow the Air Force to conceptualize training as the peacetime manifestation of war. That is, ground-based pilot training can now move beyond simply training procedural skills to training wartime mission skills on a much more frequent basis than past training range training has allowed. We discuss R&D advances in three key areas that will truly allow the Air Force to train as it intends to fight. These three areas are "Warfighter Training Behavioral Research", "Distributed Mission Training Engineering Development", and "Night Vision Device Training R&D". Under each of these three main categories of R&D we discuss specific advances made in our laboratory. We also discuss future directions that we believe aircrew R&D should advance in order to provide synthetic training environments that will allow the full measure of warfighting skills to be trained.

I. INTRODUCTION

The US Air Force's Major Commands are committed to an aggressive process of continual improvement in their aircrew training programs. More complex training requirements are continually evolving at the same time that training resources are becoming scarce. This combination of doing more with less has heightened Air Force interest in discovering and effectively using innovative training techniques and technologies.

For example, a "Four Star Summit" on modeling and simulation was held by the Air Force Chief of Staff, Gen. Ronald Fogleman, in June of 1995. The effective use of modeling and simulation for all types of training and mission rehearsal was a major topic of discussion at the Summit. The recently developed capability to link a variety of training simulators, constructive models, and live aircraft in a wide area network to accomplish mission training was endorsed by the Air Force leadership. In addition, the Air Force Scientific Advisory Board has pointed out the utility of using modeling and simulation to increase the scope and realism of warfighter training at an affordable cost.

As powerful as these new modeling and simulation tools can be, they can only be effectively used if all aspects of quality training system development are understood. The Armstrong Laboratory's Aircrew Training Research Division (AL/HRA) has a robust training R&D program which is described in this paper. The program is aimed at producing a solid research foundation upon which sound training system development principles can be based. Modeling and simulation are a major part of AL/HRA's "toolkit", but it's AL/HRA's skilled scientists, engineers, computer scientists, and pilots who bring the true training systems perspective to all of the R&D that we produce.

The work at AL/HRA is concentrated into three main areas:

- Training the Warfighter behavioral research
- Distributed Mission Training Engineering Development
- Night Vision Device Aircrew Training Behavioral Research and Engineering Development

This paper describes all three areas, and shows the interaction between them. Our work in these areas is integrated and not mutually exclusive. Major R&D innovations at our Division are described along with significant R&D efforts we see on the horizon. We have decided in this paper to give a broadbrush view of a variety of R&D activities, rather than give detailed descriptions of just a few R&D topics. Please contact or visit us if you would like more information on any of these activities.

II. TRAINING THE WARFIGHTER BEHAVIORAL RESEARCH

Training Guidelines for Multiship Simulation Training

Recent advances in simulator networking have allowed the construction of large confederations of disparate simulators. A variety of aircraft simulators can now be linked, and in the future, as simulator costs continue to drop, we expect to see literally hundreds of training devices from the Air Force, other US military services and allied countries conduct joint training together. The effectiveness of such training will largely depend on the quality of training guidelines that can be given to those who conduct such training. Experience thus far has shown that merely using the same training techniques in networked simulators for training combat skills as are used on training ranges is inefficient and does not take full advantage of the simulators unique advantages. The simulated combat environment provides special instructional advantages that are not found on ranges, which have a variety of training constraints. For example, flight training does not allow real-time kill removal during an engagement, which can significantly change the outcome of the training engagement. Range training restricts the electronic warfare aspect of the battle due to security constraints. Simulator training allows for a complete range of electronic warfare tactics and equipment to be conducted. Briefing as teams can be more efficiently performed in simulated environments than with range training, especially when geographically dispersed units are involved.

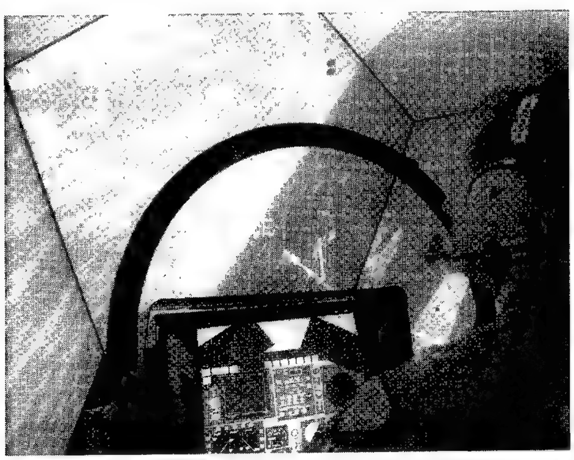
AL/HRA's work with multiship training is aimed at developing training guidelines that will allow instructors and trainees to take maximum advantage of synthetic environments. We are producing guidelines based upon empirical data and empirical experience garnered through a variety of studies in our multiship simulators. We are interested in helping major user commands de-

Paper presented at the AMP Symposium on "Selection and Training Advances in Aviation", held in Prague, Czech Republic, in May 1996, and published in CP-588.

velop multiship training strategies. These strategies define; who should be trained, what skills and knowledge should be trained, where and when the training should take place, and how the training should be evaluated. Our multiship studies examine novel training interventions that are allowed for the first time by synthetic environments. We also attempt to determine whether existing training technologies will be sufficient to allow multiship combat skills to be trained, and if not what new technologies should be developed.

Combat Situational Awareness Research

At present, there is considerable interest in situational awareness (SA). Loss of SA is considered to be a major factor in many aviation accidents. From an operational standpoint, there is also interest in SA as an important element that largely determines success within a tactical aviation environment. Against this backdrop of general interest in SA across a variety of domains, the Armstrong Laboratory recently completed a large-scale investigation of SA within the operational fighter community in response to a request from the Air Force Chief of Staff. Questions posed by the Chief included: What is it? Can we measure it? Is it learned or does it represent some type of basic ability or characteristic that some have and others don't? From a research standpoint, these questions translated into issues of measurement, selection, and training, which the laboratory has been researching for some years.



MULTIRAD Environment

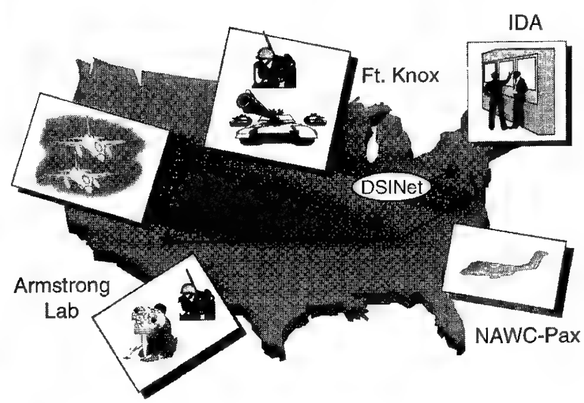
AL/HRA was responsible for two main thrusts in the larger Armstrong Laboratory effort: the development of measures and the study of the role of training in developing SA. In particular, a number of assessment tools, based on a combination of supervisor, peer, and self-report judgments, were successfully developed for measuring SA in operational fighter squadrons. Additionally, a series of SA simulation scenarios were developed for the Division's Multiship R&D simulation facility described elsewhere in this paper. Of those individuals evaluated in the operational squadrons, a sample of 40 pilots were evaluated using the specially developed scenarios that are representative of a high fidelity F-15 combat mission environment. The results point to the salience of training rather than selection as the prime way of enhancing SA in the combat environment. Moreover, the data suggest that multiship simulation training can be an important tool in developing and maintaining SA within our operational forces. Current efforts are focused on an in-depth analysis of data that were gathered in the simulation portion of the study.

An attempt is being made to identify those individual characteristics that distinguish those pilots who performed extremely well versus those who performed poorly in the simulated combat environment. If such characteristics can be reliably measured, it becomes possible to design training programs that target the development of those skills that lead to expert performance. An additional finding of the study was the potential value of eye-movement recordings as a training tool. An effort is currently underway to explore the benefit of these recordings as a tool for providing real-time feedback as well as post-mission debriefing.

Joint and Multi-Service Distributed Training Research

The joint and Multi-Service Distributed Training Testbed (JMDT2) is a multi-service research and development program.

The JMDT2 provides the services a common training effectiveness testbed. Participants use this testbed to investigate multi-service training strategies and methods. The testbed provides a continuing means to investigate multi-service training effectiveness issues. These training effectiveness issues include the role of instructors in distributed interactive simulations, multi-service versus individual service training feedback, and methods of maximizing training value for each individual participant.



Multiservice distributed training testbed for close air support.

The testbed includes a network of geographically distributed simulators. These simulators communicate with each other over a wide area network using Distributed Interactive Simulation communication protocols. This network includes armor simulators at Ft. Knox as well as aircraft simulators at the Naval Air Warfare Center and at Armstrong laboratory.

Initial research has focused on training the execution of close air support. Close air support was selected because it requires the synchronization of both command and control and tactical elements between the services. Plans are currently being formulated to extend the JMDT2 testbed to address training research issues involving air-to-air combat and joint fire support. Data

collected to date indicates that JMDT2 provides effective training for a variety of combat tasks.

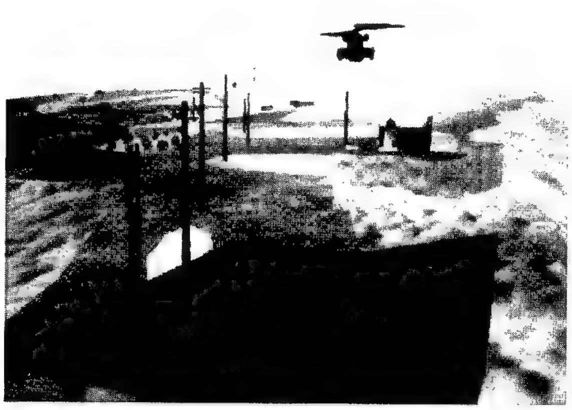
Armstrong Laboratory is contributing to both the training and engineering aspects of this program. Training researchers from AL/HRA in cooperation with researchers from the other services are identifying training objectives, developing performance measures, and designing training scenarios. AL/HRA personnel are responsible for network integration and communication. In addition, AL/HRA simulation technologies involving aircrew training devices, visual displays, computer image generators, and long-haul secure networking are among the enabling technologies needed to establish the testbed.

Special Operations Forces Training and Mission Rehearsal Research

The Air Force Special Operations community has embarked on several major modernization programs to enhance training and provide simulation-based mission rehearsal capabilities for the crew members of all special operations weapon systems. The first element to be delivered was the MH-53J Weapon System Trainer (WST)/Mission Rehearsal System, which was accepted by the 58th Operations Group (58 OG) at Kirtland AFB NM in 1990. The 58 OG training and rehearsal system has since been expanded to include TH-53A and MH-60G helicopter simulators, an electronic combat environment simulator, and a training observation center that allows training in any of the simulators to be monitored at a centralized facility.

The 58 OG and AL/HRA have formed a research partnership to address such issues, how new simulation innovations impact the mission preparation process and ultimately, the ability to accomplish the mission. A highly related issue is how to structure the mission preparation process in a way that uses these rehearsal capabilities to best advantage.

AL/HRA and 58 OG recently completed an initial assessment of MH-53J Mission Rehearsal System effectiveness. Crew reaction to this simulation-based rehearsal capability were uniformly positive. Most pilots reported that rehearsal in the simulator resulted in a better understanding of the mission plan and an increased probability of mission success.



A scene generated by the MH-53J Weapon System Trainer/Mission Rehearsal System.

AL/HRA is currently developing utilization strategies using the multi-ship, interactive environment for rotary-wing airframes at the 58 OG. AL/HRA sponsored the creation of a model that depicts the mission preparation activities performed by Combat Talon I (MC-130E) aircrews. The basic flow of events was depicted along with information gathered and used, decisions made throughout the process, mission planning tools used, products generated, and quality metrics used to assess the plan.

This model has been expanded to incorporate MH-53J mission preparation, leading to a general mission preparation model for any Air Force Special Operations air frame. The model addresses both single-ship and multi-ship missions. We also developed a human activity system model of simulation-based rehearsal that identifies (1) many functions throughout mission preparation where modeling and simulation can improve the process, (2) the essential elements of simulation-based rehearsal including the varied people who must be involved, and (3) processes to harness the power of simulation in support of mission preparation.

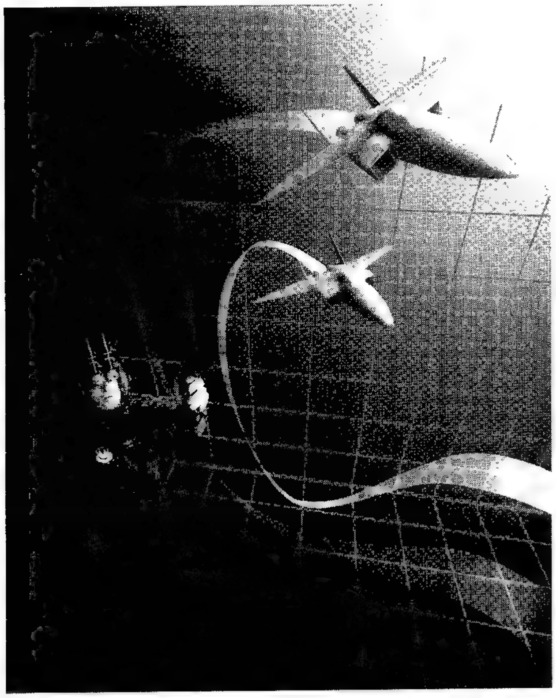
We are beginning to investigate simulation-based combat mission training issues in conjunction with the 58th OG, focusing on crew coordination and team training. This research will initially address HC-130P training, but will be expanded to incorporate rotary-wing training and multi-ship (rotary-wing and fixed-wing) training. Specific objectives are: (1) identify, develop, and validate measures of crew and team performance that can be used either in simulators or in flight; and (2) provide a framework for generating information from training and rehearsal performance that can be used to accurately assess the operational readiness of crews and teams for complex joint-service missions. The addition of the aerial gunner/scanner simulator to the training capabilities at the 58th OG in 1996 will provide an opportunity to ascertain how modeling and simulation for the entire flight crew impacts subsequent performance in training flights and in subsequent operational assignments.

Virtual Environment Visualization Training Research

Spatial awareness, the ability to apprehend the spatial parameters of an air-combat situation presents a difficult learning problem because the operator must mentally visualize a three-dimensional (3-D) environment by reading and interpreting 2-D displays. However, the technology is now available to supply trainees with a more realistic, 3-D view of the situation as it unfolds in time. This technology, variously called "virtual reality" or "virtual environment," is capable of giving Air Force trainees the ability to experience firsthand the spatial situation of the air combat arena in a computer-generated virtual world.

The promise of virtual environment technologies is that the once rigid boundary separating mind and machine can be blurred. The user is free to interact intuitively with objects and events in a 3-D world which exists solely to support task demands. Through this interaction, the user may experience psychological immersion, or 'presence' in the synthetic world, thereby heightening the vividness and impact of the training encounter. The virtual environment visualization training systems being designed at Armstrong Laboratory capitalize on these attributes to aid student pilots and ground control operators to visualize, understand, and implement air-to-air intercepts. Three virtual environment training systems are available for spatial awareness training: a head-up display (HUD)/radar symbology training, a debrief interface, and a ground control station.

The Spatial Cognition Multi-media Trainer is designed to augment academic instruction with an interactive tool which allows the trainee to practice visualization skills under conditions that mimic the in-flight spatial problem-solving situation. Within the virtual environment, the student views HUD information specifying the target's location and stereoscopic model representing the target. Using a six-degree-of-freedom input device, the student positions the model plane to match the HUD. The system provides feedback in the form of a second model which accurately represents the HUD information. To enhance the realism of this virtual environment display, the out-of-window view of the fighter's airspace accurately maps the target's location in virtual airspace visually and kinesthetically into the room in which the system is housed. Correspondence between real and virtual worlds, coupled with head-tracked imagery and wide field of view capitalizes on the psychological immersion of virtual-world technologies.



A virtual environment station.

The Virtual Environment Debrief interface was developed to be used in conjunction with Armstrong Laboratory's F-16 Air Intercept Trainer (AIT), a part-task trainer which offers concentrated practice using Hands-On Throttle and Stick (HOTAS) to accomplish radar air intercept training. Throughout the simulated sortie, the AIT records mission performance by time sampling the spatial locations of all combatants and mission-critical event information. The data are ported to a low-cost, commercially available, microcomputer for projection into a stereoscopic helmet-mounted display. The virtual world in this display maps a 40-mile square airspace to the real world coordinates of a room measuring 10' x 10' x 8' (H). The three-dimensional spatial coordinates of the aircraft (ownship and up to 5 targets) as they unfold during the scenario are projected into this world. Critical intercept events (e.g., radar mode) are displayed at the time and place of their occurrence.

To increase opportunities for gaining insight from the virtualized intercept, the debrief system also provides an interactive human/computer interface which enables the user to actively explore the data set—assuming a new viewing angle, zooming, panning and so forth. Using a commercially-available head-tracking system, the pilot may move anywhere within the three-dimensional world and assume any orientation relative to that world. This allows the pilot to examine, in detail, points along the trajectory at which critical changes in the spatial relationships of the ownship and target occurred. The real-time image generation system is designed to project imagery appropriate to the gaze direction as interpreted by the head-tracking system. Any user familiar with computers, simulators, or video arcade games can readily adapt to using the virtual environment debrief interface.

The Ground Control Intercept (GCI) operator confronts a spatial awareness problem very similar to that encountered by the fighter pilot—creating a mental model of a 3-D situation by reading and interpreting a 2-D display. The Virtual Environment Ground Command/Control System was developed for training GCI operators to support fighter aircrews through the acquisition and maintenance of spatial awareness over the vast expanse of airspace observed by ground-based and airborne radar systems.

When coupled with Armstrong Laboratory's Mission Support System (MSS), the ground control interface is capable of interacting with a variety of simulators as well as the Distributed Interactive Simulation (DIS) Network for real-time ground communications during a simulated wargame. The data are ported to a Silicon Graphics Crimson™ workstation for generation of stereoscopic imagery in a high resolution helmet-mounted display. In accord with the operating constraints of existing GCI systems, the spatial locations of all combatants and mission-critical event information are time sampled and updated at the rate of a single radar scan. For unconstrained realism in the virtual environment, the data also may be updated to 30Hz.

The virtual world of ground communications is austere, consisting of a simple wireframe terrain spanning a hundred miles in each direction. To facilitate surveillance of the airspace, the Ground Command/Control System allows the operator to actively explore the data set under two interactive modes. First, using the helmet-mounted head-tracking system, the operator may scrutinize a dogfight at close range and from a variety of viewpoints. For global surveillance, the operator may fly through the vast three-dimensional world by using a hand-held six-degree-of-freedom input device. Simple color-coded icons represent friendly and hostile aircraft. The icons' movements in the virtual world correspond to the real-time movements of the simulated aircraft. To monitor the activities of a single hostile relative to the friendly fighter, the operator may 'hook' a target icon. Upon acquiring a hook, a vector connects the two aircraft and indicates the target's relative position and heading. A pull-down menu provides additional information about each friendly and hostile aircraft and is displayed on a 2-D screen that moves with the observer.

Visual Training Research

The role of visual system technology is critical in providing fully immersive fighting environments. Advances in visual simulation technology have been made in image generation, display,

and database systems. However, many of these advances have not been tested in an operational environment and it is not yet clear that they will fully support current and future simulation training requirements. The goals of the visual training research program are to define the functional requirements for visual systems and to define the relationship between visual system capability and training value. Previous research concentrated on five areas:

(1) scene content for low altitude flight,

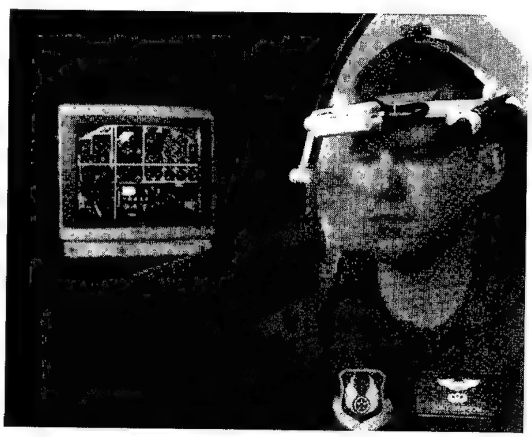
(2) color perception control,

(3) field of view requirements,

(4) spatial and temporal perception,

(5 trade-offs between display brightness, contrast and resolution.

This research resulted in specific recommendations for display design, image generation requirements, and database capabilities. Findings specify the level of terrain resolution required for low altitude flight, the level of object density and realism required, the effects of image generation update rate on object recognition and motion perception, the relationship between ground texture characteristics and altitude and velocity perception, a software control procedure for device independent color matching and achieving naturalistic (i.e., "real world") appearing colors, and the effects of display characteristics on the occurrence of simulator side effects such a eye strain and headaches. In addition, a comprehensive annotated bibliography of visual display-related research was published during the last year which can be used by the research and engineering communities as a reference document.



Eye Tracker

Current research is focused on:

(1) defining the requirements for dissimilar networked visual systems used in distributed mission training,

(2) object size and distance and motion perception as it relates to display viewing distance and level of scene detail,

(3) naturalistic color perception in mesopic displays,

(4) the effects of stereoscopic display disparities on spatial perception, especially as related to surface slant and inclination, and

(5) the use of an eye-tracking device as a training aid.

A laboratory research program has been initiated that will lead to the development of functional performance specifications for use in simulator visual displays ranging in application from individualized training to large-force joint exercises. To support this research program, AL/HRA has dedicated a visual display and imagery laboratory which includes rear projection screens, single and multiple light valve projectors, SGI graphic workstations, and access to modern image generation systems. We have also developed an eye-tracking laboratory which includes several eye-tracking devices, software to conduct on-line and off-line analyses of eye movements, and a portable head-mounted eye position monitoring and recording system. In addition, AL/HRA facilities include fiber optic head-mounted displays, two full field-of-view visual displays, and a variety of fighter aircraft cockpit capabilities.

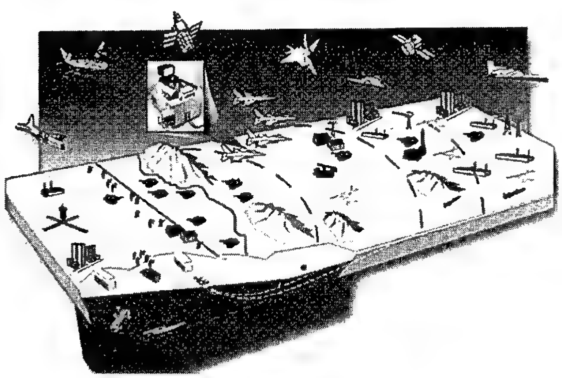
III. DISTRIBUTED MISSION TRAINING (DMT) ENGINEERING DEVELOPMENT

In the past, aircrew training has been heavily dependent on actual aircraft as the only realistic media for providing mission training. Aircraft training devices were used predominantly to better prepare the aircrew to more effectively use limited flying hours. However, increasing training requirements coupled with expanding peacetime constraints have reduced both the quality and quantity of realistic, available training for our aircrews. Now, with the dramatic improvements in the capability and affordability of advanced distributed simulation (ADS) technologies, aircrew training can be significantly improved using the concept of distributed mission training.

Distributed training allows multiple players at multiple sites to engage in training scenarios ranging from individual and team participation up to full theater level battles. It allows participation using nearly any type of networkable training device or the actual weapon system. Additionally, computer generated or constructive forces can be used to substantially robust the scenario. This combination of live, virtual and constructive environments will allow nearly unlimited training opportunities for service, joint and combined forces from their own location or a deployed training site. This expanding capability will provide on-demand, realistic training opportunities for all aircrews in the future by overcoming many of the current constraints that limit training effectiveness and arbitrarily cap readiness levels. Distributed mission training will dramatically improve the quality and quantity of aircrew training and will provide the most significant increase in readiness since the inception of RED FLAG and the AGGRESSOR programs in the 1970s.

Aircrews in low cost, high fidelity unit level simulators with full visual systems will be immersed in the training arena or the joint synthetic battlespace. There they will network and team with other air, ground, sea, and space forces to execute the air tasking order in a specific training scenario developed and managed by respective battlestaffs. At other times, units will conduct local training or workups for major exercises using the system. However, to make this a reality, many of the enabling technologies must be significantly improved and made affordable. While low-

cost cockpits are available, these devices must now become surrogate weapon systems rather than superficial emulations that merely complement the aircraft. Visual and cuing systems must adequately represent the environment to allow the players to execute their missions. The thumbnail criteria of 20/20 visual acuity represents a significant leap in technology and affordability. Networking requirements include local, long-haul and multilevel security challenges to reliably connect disparate sites around the world. Network interface units and Distributed Interactive Simulation (DIS) protocols must be expanded to accommodate massive amounts of information and traffic generated by thousands of entities. Mission control stations, threat systems and mission support stations must be universalized and standardized to provide mission planning, coordination and execution capabilities to the warfighters. Brief and debrief capabilities must be part of the system to maximize training and to address safety issues.



Joint Synthetic Battlespace

The laboratory is supporting the development, demonstration, evaluation, and transition of those enabling technologies needed for effective, affordable distributed mission training for the aircrews. Those efforts capitalize on the Multiship Research and Development program and other numerous initiatives designed to improve capability and affordability of ground-based training.

DMT Cockpit Simulation Technologies

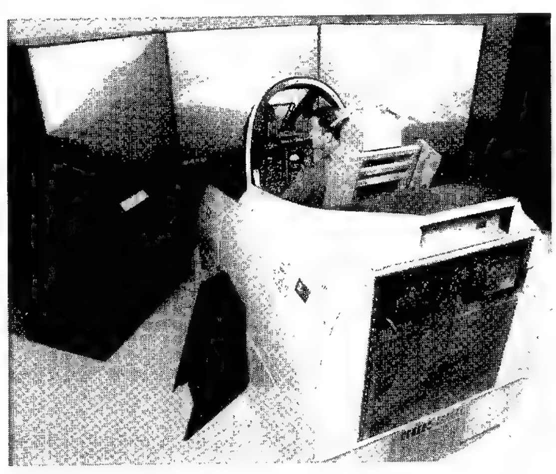
The Multi-task Trainer(MTT)/Unit Level Training (ULT) program was initiated specifically to address unit-level training. The unit environment requires reducing the life cycle costs, space, power, and maintenance requirements while providing experienced pilots equivalent fidelity and systems concurrency with their aircraft. A simulator at the squadron must provide individual stand-alone training , instructor-initiated training, and tactics, team and mission training — all from the same device and control console. The MTT has provided high fidelity and concurrency via the use of converted aircraft operational flight programs (OFPs); team training via local and long-haul networking; sensor and weapons training via correlated sensor systems; and deployment support to forward operating locations via its self-contained design, which then provides the cornerstone of mission training and future developments.

The MTT/ULT cockpit is functionally equivalent to its respective aircraft. The full fidelity instrumentation and controls are essential for a complete range of emergency procedures (EP) training. A single MTT/ULT has capabilities to train operational aircrews in a variety of skills. Networked with other MTT/ULTs, training impact can be multiplied for team training exercises and tactics.

Such features make the MTT/ULT design eminently suitable for use in operational squadrons. Efficiency and reliability were very high during in-squadron testing of the F-16 MTT. Operating on three 20-amp, 110-volt power outlets in a standard office environment, the F-16 MTT requires no external support. It can be quickly dismantled and can pass through a 36" doorway for ease of transport. The F-16 MTT fits virtually any squadron setting and could probably accompany a unit to the combat zone. The MTT requires three 20-amp, 110 volt power outlets in a standard office environment. It can be quickly dismantled and can pass through a 36" doorway for ease of transport. The F-16 MTT fits virtually any squadron setting and could probably accompany a unit to the combat zone.

In October 1993, the F-16 MTT went through extensive testing over a three-week period, and reached a major milestone of becoming the first deployable training device to be simulator certified. Certification attests to the high fidelity and reliability of the MTT software and hardware.

To shortcut software development, the F-16 MTT/ULT uses existing Air Force-owned operational flight trainer (OFT) computer code along with aircraft OFP software from the aircraft systems' line replaceable units (LRU). Aircraft software was used to ensure a direct and maintainable correspondence of the trainer to the aircraft (concurrency). OFT and LRU software was converted to run at the 50Hz rate of the aircraft microprocessors. Use of government-owned software kept development risk and cost low while maintaining the highest level of simulation fidelity. It also ensured MTT/ULT concurrency with the aircraft as evidenced by recertification of the F-16 MTT with the SCU-2 avionics upgrade ahead of the aircraft.



Recycled A-10 OFT using MTT architecture with SE2000 visual.

As investment technology, the MTT/ULT program sets a new standard for cost-to-capability of simulators and allows for easy

expansion for other aircraft. MTT/ULT projects target training requirements and exploit modern technology to achieve fidelity and concurrency. A-10 OFTs have been quickly recycled using MTT architecture, while AL/HRA is on line to convert the A-10 LASTE software. The A-10 MTT was used to prototype other space-saving and increased fidelity technologies such as new digital control loading devices which are also targeted for use in the C-130 ULT. The C-130H3 ULT will revolutionize training availability and quality for the wide body aircraft community. Existing simulators use motion-based platform systems that are expensive to procure and maintain and require specialized facilities and maintainers. A wide body, unit-level trainer will require an MTT-based high fidelity cockpit, the latest in graphical user interface (GUI) operator consoles, and modern technology for providing necessary cuing so that it will fit in existing squadron facilities. Although not quite as mobile as the F-16 MTT, the C-130 ULT has still been designed for modular assembly with quick disconnect points for rapid deployment to any needed location. The F-16 MTT occupies a floor area of only 5' x 6', while the C-130 dimensions are 14'L x 10'W x 12'H. Instead of treating F-16, A-10 and C-130 simulators as three separate and distinct training systems, Armstrong Laboratory, through its quality approach to training, has been able to standardize hardware components through the use of open VME architecture. This approach is inexpensive and simple, yet flexible and elegant for self-contained simulators and will greatly reduce the logistics required by users to support numerous unit-level, high-fidelity training systems. All MTTs and ULTs are designed with inherent local and long-haul networking capabilities to enable the devices to be used in joint service DIS exercises promoting greater interoperability among services.

With the F-16, A-10, and C-130 MTT/ULT, AL/HRA is continually demonstrating how advanced technology can make state-of-the-art simulation affordable and available to aircrews. The size and cost of the conventional F-16 simulator (OFT) has been reduced by a factor of 10, and the C-130 ULT will be higher fidelity than the WST at approximately one-third the cost. Fidelity combined with the compactness of a unit trainer that is self-contained with all computational systems, input/output linkages, control loaders, cooling and operator console, and modest power requirements make the MTT mobile, flexible, and affordable.

Our Division has also demonstrated the efficacy of "recycling" old, expensive simulators using the new architecture and rehosted software at a tremendous savings.

Visual System Technologies

An "inexpensive" answer to tactical simulation.

In order to effectively prepare for combat, a training device needs to allow the aircrew to employ the weapon system as they would in an actual conflict. The objective of this program is to develop and demonstrate a significantly more cost-effective display capability with the flexibility to address a variety of weapon system simulation requirements.

The DART series of displays are located in the TEMPEST facility of AL/HRA, at Williams Gateway Airport in Mesa, AZ. These displays capitalize on the trend that image generators (IG) will soon be inexpensive enough to make it cost effective to wrap many channels of imagery around a cockpit. This display approach explores the arena of low-cost display devices which achieve sufficient fidelity to provide a useful training tool.

The original DART system is configured as a rear screen projected dodecahedron with nine channels of imagery surrounding the design eyepoint. The screens used are flat, have a net gain of one, and are abutted with gaps of approximately a centimeter. The projectors are off-the-shelf, CRT-based, 2000-line systems. The result is wraparound real imagery, presented about 37 inches away, with luminance levels of 10 footLamberts at the edge of a screen, rising to 25 footLamberts at the center. The resolution is 4.25 arc minutes/pixel and the field of regard 360 degrees horizontally by 260 degrees vertically. With eight channels on, the contrast ratio has been measured at 50:1. A Polhemus head-tracker is used to determine where imagery is not required so that six IG channels can be channel switched to cover the nine available projectors. Six channels are sufficient to present the perception of projectors blinking on and off in the pilot's peripheral vision. A rear-screen mounted monochrome green projector provides an effective representation of an F-16C or F-15C head-up display.

Typical imagery in front half of Mini-DART.

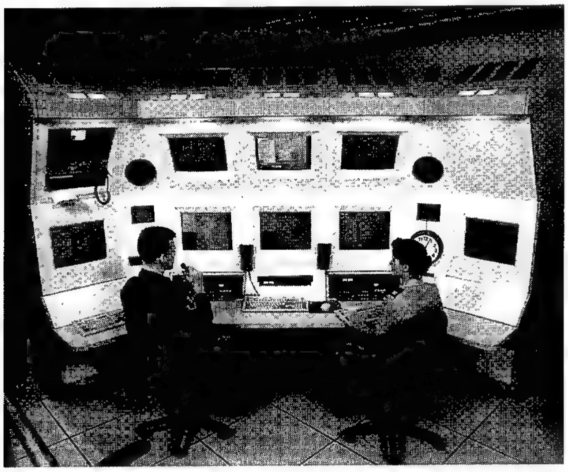
The Mini-Dart deviates from the original DART approach having been constructed of rectangular and trapezoidal screens with a 24-inch screen viewing distance which is significantly closed than the 37-inch screen viewing distance demonstrated with the DART. This design is more compact making it capable of fitting within a 10-foot ceiling height and it requires only four image generator channels to cover its eight wrap-around screens. Finally, the four-screen deployable DART is similar to the front half of the Mini-DART with each side screen wrapped 30 degrees past half way around.

Future refinements to the DART concept will include the development of a helmet-mounted, area-of-interest capability to provide the high resolution for the current DART system, and alternative higher resolution projectors employing background rasters, mini-rasters and calligraphic imagery in order to increase the display resolution while reducing system complexity and cost. As part of this effort, an interface standard is being explored which will allow the government to employ current valuable image generation capabilities aggregated with evolving high resolution target imagery for graduated increases in display fidelity.

Training System Control Technologies

The Multiship Support System (MSS) supports multiship training research by providing mission planning, initialization and control, performance monitoring and measurement, data collection, debrief, and operator voice communication control for networked simulation devices. MSS communicates using Distributed Interactive Simulation (DIS) standard protocol data units. With the exception of the video tape recordings made for debrief, it is transparent to the MSS whether a simulator is on the local network or connected over a wide-area network.

The Multiship Support System consists of a real-time support station, a mission planning station, two debrief stations, and a large-scale display facility.



Simulation Management Station (SiMan)

The Simulation Management (SiMan) station is the nerve center of the MSS. It provides the scenario planning, initialization and control, performance monitoring and measurement, and data collection functions of the MSS. Along with the mission planning station, the real-time support station provides pre-mission setup and initialization as well as the real-time control for the operator/researcher. Displays in the real-time support station show a repeat of the out-the-window view from two selected flight simulators, the instrument displays from two flight simulators, a repeat of the ground control intercept (GCI) or airborne warning and control system (AWACS) simulators display, an operator display from which the exercise can be set up and controlled, a "God's-eye view" and perspective view display for initializing and monitoring the exercise, and a researcher display. A summary of the exercise can be selected at the researcher display alternating with a display designed and created by the researcher. As soon as an exercise is completed, the summary display is printed and within minutes the data and video tapes are moved to the debrief station for the debrief to begin.

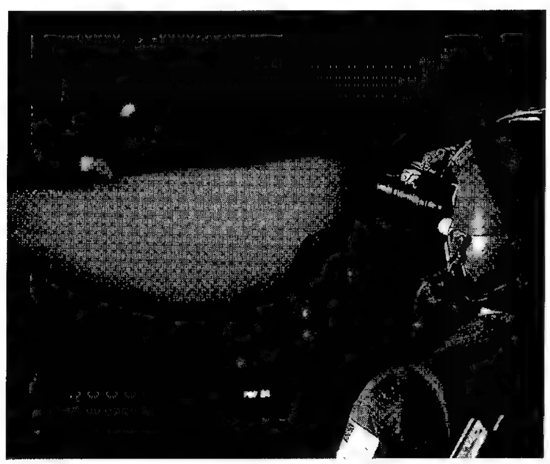
The mission planning station provides a way to input mission planning data in a manner similar to the method used for the actual aircraft. The data are written to floppy disks and moved to the SiMan station for forwarding to the flight simulators as part of the initialization procedure. Mission planning is done on a personal computer system that is derived form the mission planning system used in operational F-16 units. The software has been modified to support mission planning for other types of aircraft in addition to the F-16.

The debrief stations provide post-mission support. The displays consist of video playback of two selected cockpit displays and of the AWACS station, graphically generated out-the-window displays for any two entities on the network, and a controllable God's-eye/perspective view of the exercise. The students may use the perspective display to watch the exercise from different points of view, providing a better picture.

IV. NIGHT VISION DEVICE TRAINING R&D

The capability afforded by night vision devices (NVD) for the conduct of nighttime military operations has literally revolutionized modern warfare. Certainly, the recent war in the Persian Gulf was a convincing demonstration of an overwhelming military advantage due in large part to night vision technology. NVDs, primarily night vision goggles (NVG) and forward-looking infrared (FLIR) sensors have become an integral part of night operations for many aircraft, both rotary and fixed-wing. While NVDs impart a significantly increased capability over unaided night vision, their restricted field of view and reduced resolution (visual acuity) are somewhat deficient when compared to unaided day vision. In addition, the imagery produced by NVDs has unique characteristics that require specific interpretive techniques which must be learned by the operator. These aspects of night vision technology have a significant impact on operational procedures and training requirements.

It is a certainty that nighttime military operations will receive even more emphasis in the future, but training at night will be constrained by shrinking resources, airspace restrictions, and reduced manning. Cost-effective, ground-based training systems and facilities will be essential.



NVG-Compatible Simulator

The Night Vision Program of the Aircrew Training Research Division, was established to meet the operational training requirements of both existing and future systems. After thorough review of existing DoD NVD aircrew training programs, research objectives were developed with user inputs and contributions by subject-matter experts. The first completed product was the NVG Test Lane, which combines a specially designed NVG resolu-

tion chart (developed at AL/CFHV) and standardized light source with a comprehensive set of adjustment and assessment procedures. The NVG Test Lane provides, for the first time, a practical means by which NVGs can be adequately adjusted and functionally assessed in an operational setting. This capability is vital not only for initial NVG training, but also for routine preflight procedures in operational units.

A Basic Instructor Course for NVG ground training has also been produced on videodisc and is now in use by all Air Force major commands. Individual modules include:

- Visual Physiology and Spatial Orientation,
- Fatigue and Circadian Rhythm,
- The Night Environment and NVD Theory,
- NVG Adjustment and Pre-flight Assessment Procedures, and
- Cockpit Procedures.

Applied visual research is under way to enhance our understanding of aided night vision. This includes the investigation of size and distance perception with NVGs, the role of unaided peripheral vision on aircrew performance during NVG-aided flight, and the effects of degraded images on perception and performance.

Future research will include the development and evaluation of a low-cost, portable night vision training system which will enable mission training and rehearsal at remote sites as well as at home base.

The objective of the NVD training research program is to produce cost-effective, comprehensive ground-based training that prepares aircrew members for the unique aspects of NVD employment and enhances Air Force operational capabilities and safety in night operations.

V. CONCLUSION

The U.S. Air Force has embarked on an initiative to revolutionize training through expanded use and application of the technologies just discussed. The result may be merely modernization of existing training programs, or more likely to total change in our training philosophy from one that predominately relies on the weapon system to one that merely uses the weapon system to validate training, to provide acclimation in the actual environment or to enhance long-term experience. All the rest will be accomplished in simulated surrogate weapon systems that are networked with the rest of the combat participants, friends or foes. In either scenario, considerable research and development will be required to produce the needed capabilities and to validate the effects.

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TRAINING OF AIRCREW DECISION MAKING

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SUMMARY

Aircrew decision making is one central element of the CRM-training course for cockpit crews which was developed recently by the DLR-Department of Aviation and Space Psychology in cooperation with Lufthansa German Airlines and Condor. Examples of the course contents and methods are illustrated. As a framework for the training units of aircrew decision making the FOR-DEC model is proposed. FOR-DEC is an acronym which stands for six different phases of the decision making process: Facts, Options, Risks & Benefits, Decision, Execution and Check. The paper describes how this model is integrated into the training units on team problem solving and decision making. First evaluation results of the course are shown which are based on the seminar critiques of 750 participants. These feedbacks are very positive in regard to the overall relevance of the course contents and methods. However, they also indicate the importance of authentic in-house scenarios for the effectiveness of the seminar processes.

INTRODUCTION

NASA and FAA research on the causal or contributing factors of air carrier accidents have shown that a high degree of technical proficiency of the pilots is a necessary but not a sufficient condition for a safe and efficient flight. Ineffective cooperation of the crew members cannot be compensated by excellent piloting skills of the individual and vice versa. Many problems encountered by flightcrews had little to do with the technical aspects of operating in a multipilot cockpit, but were related to ineffective communication, inadequate leadership, poor workload management, and poor decision making of the crew (Ref. 1). Traditionally pilot training was focussed on the individual pilot's performance and on the skills of handling the man/machine interface. Little emphasis was given to strengthen essential competencies of managing the human interfaces between different parts of the entire crew (cockpit, cabin, dispatch, maintenance etc.). These non-technical skills of flying were supposed to emerge automatically in the course of growing flying experience. This belief was proven wrong by several human-factors related aircraft disasters.

Having realized that, Crew Resource Management trainings was introduced as a regular element into professional pilot training in many airlines during the last decade. In order to support this development the European Joint Aviation Authorities (JAA) have recently released their final version of regulations for civilian aircraft operations (JAR-OPS, Ref. 2). In the corresponding explanatory material CRM is defined as the effective utilisation of all available resources (e.g. crew members, aeroplane systems, and supporting facilities) to achieve safe and efficient operation. The main training objective is to enhance the communication and management skills of the flight crew members concerned. Furthermore it should be ensured that the flight crews complete the "major elements" of the full CRM-course over a four year recurrent training cycle.

CONTENTS AND METHODS OF THE DLR/LH CRM-COURSE

In 1992 Lufthansa German Airlines decided to reorganize their human-factors training concepts in order to include a comprehensive CRM-seminar for all line pilots. An interdisciplinary working group was set up consisting of aviation psychologists from the DLR, educationalists, training pilots and flight engineers. This combination of different backgrounds was chosen to ensure that the actual training needs of Lufthansa's and Condor's cockpit crew members are met and that the scientific research in the field of human factors is thoroughly considered (Ref. 3, 4, 5, 6). After a development period of one year this initiative designed a three days CRM course with more than 20 scheduled training hours spread over 13 main units which are moderated by familiarized pilots. From January 1994 on the course was running two times a week with a size of 15 to 16 participants. The 13 main training units can be grouped into three domains as shown in table 1: a) Communication, b) leadership and teamwork, c) judgment and decision making. A fourth important domain stress-management is included in a separate seminar. On the basis of collected seminar critiques a major revision was made in May 1994.

These training units of the DLR/LH-course reflect standard topics in relation to the European JAA-regulations which are similarly incorporated into CRM-trainings of other airlines as well. A variety of training-methods was chosen to offer several learning opportunities for the different characters and learning habits of the participants. Theory is reduced to a minimum. Emphasis was given to both structured and unstructured interactive group activities. Participants are gently encouraged to open up and talk about their own experiences in the plenum or in small groups. The whole course is based on the philosophy of *cultivating favourable attitudes towards teamwork through the improvement of communication styles and the free exchange of information among the crew in order to maximize resources for the primary task of flying the aircraft safely and making decisions efficiently without crewmembers being afflicted by unnecessary task overload*

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or underload.

TRAINING OF CREW DECISION MAKING

The final exercise of the DLR/LH CRM-seminar is a very intensive four-hour problem solving game in which the newly acquired or reactivated skills of the participants are being put to the test. A realistic aviation-related crisis scenario is simulated in the classroom which has to be managed by two parallel teams under certain time-pressure and with limited resources. The situation changes dynamically due to unexpected inputs from the facilitator. Contradictory feelings and motives are induced onto the participants through distributed roles in order to further stimulate the in-group dynamics. This scenario called "OCEANA" was originally developed by Capt. C. DuToit and further refined by A. Schiewe and Capt. M. Frohs. Communication behavior, cooperation, and contributions to the decision making process are being observed by the course facilitators for the individuals and the whole team. Afterwards in a thorough debriefing self-critiques and peer feedbacks are exchanged within the teams under supervision of the facilitator. Working as a teammember on this scenario might be somewhat stressful because of the induced time-pressure, continually changing conditions, distractions, incomplete information, and simulated personal consequences. Similar situation attributes are characteristic for the complex and highly dynamic working environment of pilots (Ref. 7). Laboratory studies have shown that the quality of individual and team decisions generally decrease substantially under such conditions due to several reasons (Ref. 8). Especially if the individual teammembers perceive a significant lack of time or other resources they tend to

- formulate a "situation-diagnosis" early and then try to confirm rather than to test it
- adopt the first problem solution developed
- be too conservative in recognizing changes in problem conditions
- be reluctant to change an erroneous commitment in light of new evidence
- ignore ambiguous or partial data
- overestimate probabilities of favourable outcomes, and underestimate probabilities of unfavourable outcomes
- reduce communication or focus on unrelated details.

It is assumed that during the first two days of the CRM-course the participants are being prepared with suitable concepts, methods, and skills to manage the described problem-solving game efficiently. That is developing an adequate strategy for the problem-solution by means of sound decision making without simply overriding anyones position. As a countermeasure against biased judgment an instrument was developed that is basic for the course, called the FOR-DEC model (Ref. 9). This model serves as a guideline to structure the communication and team interaction processes.

FOR-DEC is a synthetic word. Each letter represents one of six different stages in an "ideal" decision making process: <u>F</u>acts, <u>O</u>ptions, <u>R</u>isks & Benefits, <u>D</u>ecision, <u>E</u>xecution, <u>C</u>heck. Each stage is combined with a leading question which should direct the crew's attention step-by-step to the critical elements of the decision making process (see Figure 1).

Being in interaction with the operating environment, facts are the trigger for the decision making process. Before a decision is made information is gathered and if possible cross-checked by independent sources to reach a preliminary situation assessment. Different options are scanned without immediate evaluation. Applicability, and expected risks and benefits as well as uncertainties are made aware in the third stage. To ensure that the mental images of the situation include the relevant data, inputs and notions by all involved teammembers are indispensible contributions. Communication between the crewmembers on these stages should always be two-ways. Otherwise the available resources cannot be utilized, and the mental images of the crew members might be absolutely out of tune. Before a decision is made by the one who is in command, the crew should have a common understanding of the situation. Otherwise parts of the crew could go lost by confusion and cannot further participate in a coordinated execution or in monitoring of the chosen actions. Provided that teamwork and communication between the crew members are intact, the crew will be superior to the individual decision maker in most cases. Two or more crew members can seek more information, can generate more options, and are more consequent in estimating possible risks and benefits than a single pilot. Furthermore the tasks can be shared during execution and a helpful feedback from the crew members during the Check-phase can be a valuable learning experience.

The application of the FOR-DEC model is practised in small-group activities during different seminar units with authentic flying-scenarios, for example: a) Engine failure in cruise with ambiguous instrument readings, b) complete generator failure on departure, c) NAV-receiver unserviceable without off-flag. Also training of single stages of FOR-DEC are included into several units. For example a checklist for gathering relevant facts is introduced to counter loss of situation awareness. In creative exercises opportunity is given for training of divergent thinking and generating options. Personal experiences with risky decisions are analysed in small groups in order to retrospectively identify embedded risks and benefits. In the team exercise OCEANA we found that the FOR-DEC model helps to structure communication and group interaction processes. While working on this problem scenario the pilots often used meta-level-statements like, "let's have a look on what facts we have got, first", "does anyone can think of an option, we have not fully considered?" or "let's go back and see, whether there is anything we have overlooked". The feedback of the peers and the facilitator is appreciated by most participants. Like a mirror it can reveal personal habits as well as productive and counter-productive behavior patterns when the individual interacts with the crew in solving conflicts and finding the most promising solution for the crisis scenario.

FIRST EVALUATION RESULTS

As a first evaluation of the training outcomes at the end of each CRM-course the participants were asked to give a detailed feedback in regard to the job-relevance of the course contents and the attractiveness of the training methods. Ratings are given on 5-point-scales for each seminar unit and for the whole course. They range between "--" (1) which means content absolutely unimportant or method boring/a waste of time and "++" (5) which means content extremely useful, method very stimulating. Data of 52 seminars and 750 participants have been collected after a major revision of the course in May 1994. The distributions for the overall assessments of the course contents and methods are shown in Figure 2. Most participants rated the contents as relevant (90% rated "+" or "++", mean 4.2) and the methods as attractive (84% rated "+" or "++", mean 4.0).

Three units were rated better than the whole course in general. These are "Decision Making Strategies" with an average rating for relevance of contents of 4.6 and for attractiveness of methods of 4.3, "Problem-solving in teams" with average ratings of 4.5 for contents and 4.5 for methods, and "Situation Awareness" with average ratings of 4.5 for contents and 4.2 for methods. All of these units are related to decision making especially in crew situations. The training methods in these units are based on the analysis of case examples in small groups (two examples are authentic, one is constructed). Especially the inclusion of real in-house scenarios seems to be effective in terms of training success. During the course revision phase in April 1994 a human-factors example of the own airline was included into the unit "Situation Awareness". This led to a significant increase in the ratings (Ref. 3). In-house scenarios of the recent airline history help to counteract the pilot's attitude "this cannot happen to us".

These first evaluation data of the DLR/LH CRM-course are encouraging. However, the effects of a three-days seminar and the transfer to the working place will be limited, unless CRM-principles are integrated into the whole training philosophy of the company. Also the personality of the crewmembers cannot be changed in such a seminar. An early screening of candidates is necessary to ensure that they have the basic personal prerequisites of working effectively as a teammember. Nevertheless, the full support of the management and the consequent reinforcement by the training department for CRM-concurring behavior is absolutely necessary even if this means the investment of further training expenses. In the long run these efforts for quality will raise job-satisfaction and productivity of the personnel and will prove the credibility and the actual safety culture of the company.

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- FACTS:
  What is actually going on here?
- OPTIONS:
  What are the choices we've got?
- RISKS & BENEFITS:
  What are the pros and cons?

–

- DECISION:
  So, what shall we do after all?
- EXECUTION:
  Who shall do what, when, and how?
- CHECK:
  Is everything (still) allright?

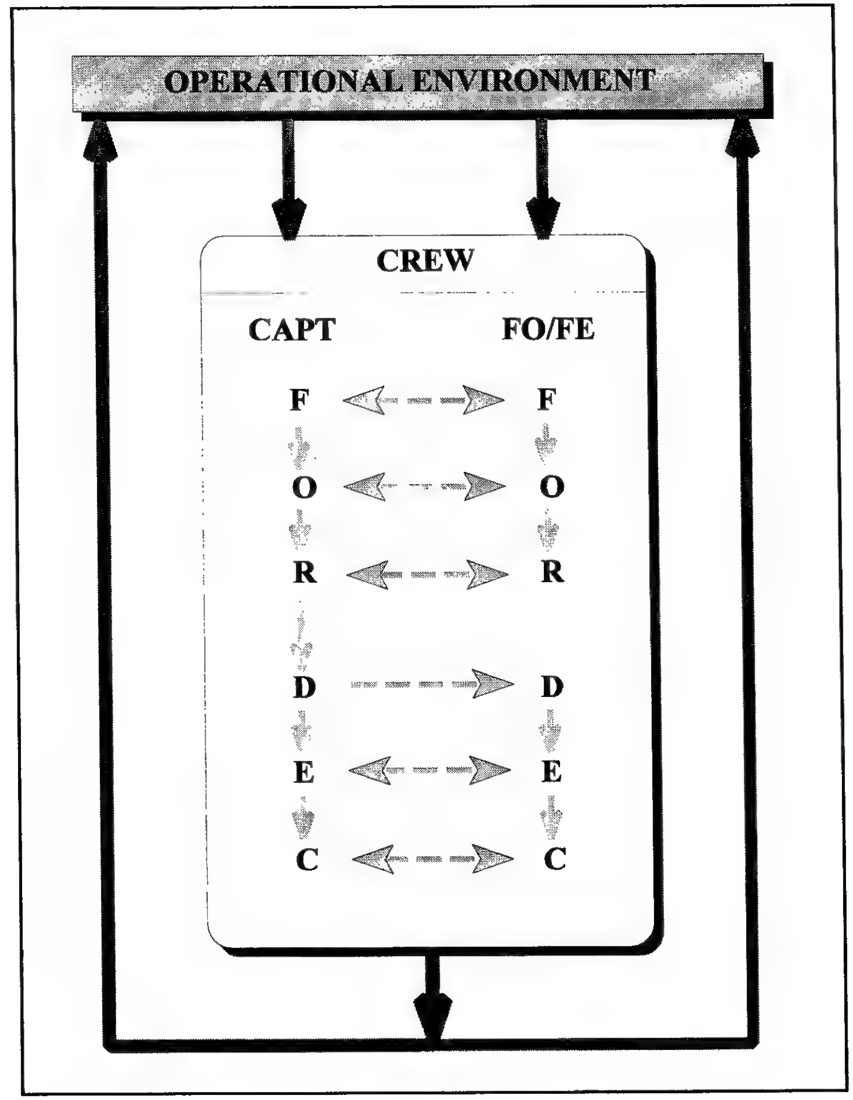

FIGURE 1: FOR-DEC model for crew decision making

FIGURE 2: Relevance of contents and attractiveness of methods for the entire CRM-course (N = 750)

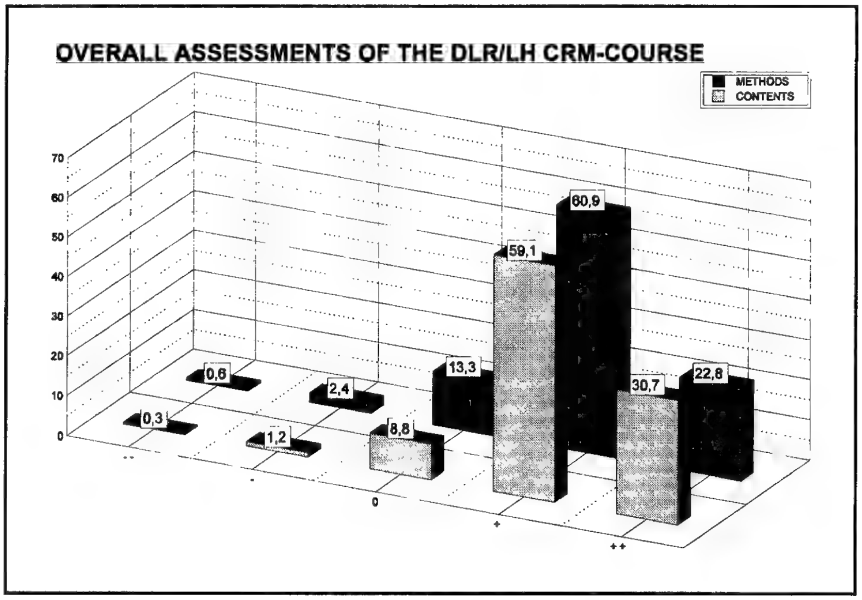

TABLE 1
Main training-units of the DLR/LH CRM-course

TRAINING-CONTENTS	TRAINING-METHODS
Communication - Inquiry and listening - Advocacy - Communication barriers and conflicts - Feedback	 - Group activity, discussion, video - Video, group discussion, lecture - Group discussion, role-play with video - Group activity, video-feedback
Leadership and teamwork - Stereotypes: The first impression - To become a team-player - Authority and assertiveness - Problem solving in teams	 - Small-group activity, discussion - Small-group activity, creative exercise - Video, activity in pairs - Crew-problem-solving game, peer-feedback
Judgment and decision making - Human error - Decision making strategies - Situation awareness - Attitudes and risk assessment - Time management and workload control	 - Lecture, video with case-example - Case-study, small-group activity - Case-study, small-group activity - Role-play, self- and peer-feedback - Video, lecture, group activity

LA FORMATION AUX FACTEURS HUMAINS POUR LES ÉQUIPAGES DE L'ARMÉE DE L'AIR FRANÇAISE

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SUMMARY
French air force has defined in 1994 with IMASSA an "human factors" policy to improve flight safety. This policy contents three ways : physical training programme, experience feedback increasing, and "human factors" training programme. This article summarises the main aspects of the definition and application of the "human factors" training programme.

1. INTRODUCTION
Depuis le début des années 80, la place des facteurs humains au sein de l'aéronautique évolue en permanence. Longtemps considérés sous les seuls aspects médicaux et physiologiques, les facteurs humains ont pris avec la psychologie, l'ergonomie cognitive et la psychosociologie une dimension qui les situent au cœur des débats sur la conception des matériels et la formation des équipages. A la suite de catastrophes aériennes survenues dans l'aviation commerciale comme l'accident de Ténériffe en 1977 où deux Boeing 747 se sont percutés au décollage, les responsables de la sécurité aérienne se sont trouvés face à un constat : des accidents se produisent avec des aéronefs n'ayant pas de pannes ou des pannes mineures et pilotés par des membres d'équipage qualifiés. Que faire pour éviter les accidents liés au comportement humain ? Les réponses peuvent être de plusieurs ordres :

- accroître l'automatisation des cockpits avec pour ambition cachée d'éliminer petit à petit l'opérateur humain,
- mettre encore plus l'accent sur la sélection et la formation technique des équipages,
- développer de nouvelles approches pour mieux prendre en compte les caractéristiques du comportement humain.

Les deux premières réponses ne sont qu'un prolongement de ce qui existent déjà et se heurtent rapidement à deux limites. La première de ces limites est représentée par les paradoxes de l'automatisation (Bainbridge, 1987 ; Rasmussen et Goodstein, 1985). Rapidement en effet, on s'est aperçu que l'automatisation permettait de résoudre certains problèmes mais paradoxalement en créait de nouveaux qui n'avait pas été envisagés (perte de certaines compétences, baisse de la charge de travail dans les phases à faible charge de travail et accroissement dans les phases à forte charge, rôle de l'homme en ultime secours lorsque la machine ne sait plus faire). La deuxième limite est l'inadéquation qu'il peut y avoir entre une politique élitiste menée à travers la sélection et la formation, et un besoin incontournable en personnels navigants pour les exploitants aéronautiques, le tout associé à des considérations économiques. On s'aperçoit rapidement qu'il faut envisager de nouvelles voies si l'on veut améliorer la sécurité.

La troisième réponse est une de ces voies. Elle est liée au développement théorique d'un corpus de connaissances sur le comportement humain. Le développement de la psychologie et de l'ergonomie cognitive au début des années 80 s'est attaché à modéliser l'activité des opérateurs en situation de travail (Amalberti, 1996). Cette modélisation a permis d'enrichir le savoir sur la perception, les capacités et limites intellectuelles humaines, la conscience de la situation, la prise de décision, la prise de risque ou le raisonnement. Parce qu'ils proviennent de résultats d'études en situation réelle de travail et non d'expérimentations en laboratoire, les nouveaux modèles se différencient des modèles existants. L'intérêt de ces nouvelles approches est d'être plus écologique car favorisant la prise en compte de la complexité des situations de travail (pression temporelle, dynamique du processus, multiplicité des informations, informations absentes ou incertaines, nécessité de prendre des décisions, etc.). Le modèle de l'être humain au travail est alors apparu sous un jour nouveau avec ses avantages, ses faiblesses, mais surtout le rôle positif de l'être humain dans la sécurité. Partant de ce constat, la notion d'erreur humaine a considérablement évolué mettant l'accent sur le côté "naturel" de l'erreur, qui est en quelque sorte

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la contrepartie de l'efficacité humaine (Reason, 1990). Il n'y a pas de mécanismes spécifiques de l'erreur mais des mécanismes de traitement de l'information qui peuvent être inadaptés aux situations rencontrées.
Parallèlement à cette approche centrée sur l'individu et à la suite d'accidents comme Challenger ou Tchernobyl en 1986, se sont développées des approches centrées sur le travail collectif et la sécurité dans les systèmes (Gras, 1995). Des mécanismes de production d'erreur à un niveau collectif ou au niveau des organisations ont été décrits et ont enrichi les connaissances sur la place de l'homme dans la sécurité.

Face à ces évolutions, il est rapidement apparu qu'améliorer les connaissances des opérateurs sur les "facteurs humains" était indispensable pour susciter une prise de conscience individuelle et collective et rendre les attitudes et les comportements plus sûrs (Helmreich, 1984). Cette réflexion qui a pris naissance dans l'aéronautique commerciale dès 1988 avec des recommandations OACI (1988), est relayée dans l'aéronautique militaire sous l'impulsion des bureaux en charge de la sécurité des vols.
L'armée de l'air française a défini officiellement en 1994 un plan "facteurs humains". L'objectif de cet article est de rapporter l'expérience Française dans la définition et la mise en place de ce plan.

2. PLAN "FACTEURS HUMAINS" DE L'ARMÉE DE L'AIR FRANÇAISE

2.1. L'élaboration du plan "facteurs humains"

Dans le but d'améliorer la sécurité des vols, l'état-major de l'armée de l'air française a décidé en 1994 de définir un plan "facteurs humains" avec le support scientifique de l'Institut de Médecine Aéronautique du Service de Santé des Armées (IMASSA). L'IMASSA, organisme du Service de Santé des Armées, est le conseiller des états-majors pour tout ce qui concerne les facteurs humains en aéronautique. L'IMASSA dispose d'un bureau "sécurité des vols" en charge de faire l'analyse "facteurs humains" des événements aériens et de dispenser un enseignement "facteurs humains" auprès des personnels navigants. Fort de ce savoir et de son expérience, l'IMASSA a participé à la définition du plan "facteurs humains" et participe depuis 1994 à sa mise en application.
Le plan "facteurs humains" signé par le chef d'état-major de l'armée de l'air se caractérise par :

- sa globalité : il envisage des actions complémentaires allant du recueil de données sur la sécurité aérienne à la diffusion du savoir "facteurs humains" aux personnels navigants ;
- sa planification dans le temps : il s'agit d'une action en profondeur, visant à modifier la formation des équipages et à faire évoluer les mentalités sur les facteurs humains et la sécurité des vols.

2.2. Contenu du plan "facteurs humains"

Le plan "facteurs humains" s'articule en trois volets :

- Premier volet : optimisation de l'entraînement physique et sportif des personnels navigants. Les personnels navigants suivront un entraînement physique et sportif adapté pour améliorer la tolérance physique aux contraintes physiologiques de plus en plus sévères du vol. Cet entraînement s'effectuera sous la responsabilité de moniteurs d'éducation physique spécialement qualifiés. L'objectif est d'avoir un suivi individuel de chaque personnel navigant avec une adaptation des programmes d'entraînement. La contiguïté des installations sportives avec les escadrons est la règle d'or pour faciliter l'accès et l'acceptation par tous. Les moniteurs d'éducation physique auront reçu par ailleurs une formation spécifique aux techniques de relaxation qu'ils dispenseront aux équipages.
- Deuxième volet : amélioration du retour d'expérience et élaboration de bases de données "facteurs humains". Le Bureau Sécurité des Vols de l'armée de l'air développe un système informatisé de retour d'expérience pour les événements aériens : existence au sein de chaque escadron d'un terminal informatique qui permettra à l'officier "sécurité des vols" de renseigner une fiche sur le déroulement d'un événement aérien, ses causes et les facteurs qui ont pu contribué à sa survenue. L'IMASSA a élaboré la partie "facteurs humains" de ces fiches en la calquant sur le modèle d'analyse "facteurs humains" développé dans sa base de données "facteurs humains" des accidents aériens (Grau et al, 1992). Il y aura donc ainsi similitude des données "facteurs humains" entre les accidents et les événements aériens. Les informations saisies dans le système informatisé de retour d'expérience seront consultables par tous les possesseurs de terminaux. En plus de cette action orientée sur les événements aériens, l'IMASSA conduit en coopération avec l'Office National des Études et Recherches en Aéronautique une réflexion sur la définition d'un système automatisé d'analyse systématique des vols centré sur les facteurs humains. Le but de cette dernière approche est d'avoir une meilleure connaissance du comportement des équipages dans leur activité aéronautique pour identifier les écarts entre pratique et réglementation et améliorer la sécurité des vols. Un tel outil n'a de pertinence que s'il envisage à la fois les aspects négatifs et positifs des comportements humains.

- Troisième volet : l'enseignement des facteurs humains doit faire partie intégrante de la formation du personnel navigant. Tout comme les connaissances aéromédicales, les connaissances sur le fonctionnement mental de l'être humain en situation de travail et plus particulièrement dans un cockpit doivent être appréhendées par le personnel navigant au même titre que les connaissances techniques aéronautiques. L'efficacité des missions et la sécurité des vols ne dépendent pas seulement des savoir-faire techniques mais aussi d'une gestion appropriée des ressources mentales à l'échelle individuelle et collective. La notion de travail collectif est évidente dans les cockpits multi-places qu'ils soient de transport ou de combat. Cette notion doit cependant être étendue au système de travail que représente le milieu aéronautique car un aéronef opère rarement seul. En effet, il fait souvent partie d'un dispositif et est toujours en liaison avec des stations terrestres ou aéroportées. Dans tous les cas, l'équipage est amené à travailler avec d'autres opérateurs (personnels navigants, contrôleurs, ...), à l'intérieur ou l'extérieur du cockpit et la réussite de la mission dépendra de la qualité des interactions entre les personnels. En poussant le raisonnement, on étend la notion de travail collectif aux aéronefs de combat monoplaces dans la mesure où le travail en patrouille est une composante essentielle du succès de la mission (Learmont et al., 1995). Ce dernier point fait l'objet depuis quelques années d'une attention particulière de la part des responsables de la sécurité des vols pour développer des produits de formation spécifiques aux aéronefs monoplaces.

Un des points du plan "facteurs humains" est d'insister sur la nécessité de faire reposer toute action de formation "facteurs humains" sur des bases scientifiques et d'éviter les approches qualifiées de "bon sens". Dans le domaine des facteurs humains, la psychologie, l'ergonomie cognitive, la psychosociologie et les sciences des organisations constituent les bases du savoir théorique. Cependant, ces bases théoriques ne peuvent constituer le corps des objectifs d'enseignement. Ces derniers doivent être pragmatiques, adaptés aux populations concernés et orientés vers une utilisation de tous les jours en situation réelle de pilotage. Sans relation directe avec les problématiques quotidiennes, ils risquent d'être rejetés par les personnels navigants.

2.3. Les formations aux facteurs humains

L'enseignement des facteurs humains est envisagé dans le cadre d'une acquisition des connaissances par le personnel navigant en deux étapes : une formation initiale en école de pilotage et une formation continue en escadron opérationnel.

2.3.1. La formation initiale a pour objectif d'apporter aux élèves des écoles de formation du personnel navigant les bases théoriques sur les facteurs humains. Le module "facteurs humains" comprend une partie classique déjà ancienne d'enseignement aéromédical et une partie nouvelle plus spécifique sur les principes du fonctionnement mental. L'enseignement est dispensé sous forme magistrale par des médecins du personnel navigant spécialement formés à l'IMASSA. L'IMASSA est responsable de la qualité de cet enseignement, à ce titre l'Institut a défini le contenu des cours, élaboré les supports pédagogiques et formé les enseignants. Les thèmes abordés dans la partie "principes du fonctionnement mental" sont : les limites et capacités intellectuelles, la prise de décision, les communications et le travail en équipage, le stress, la fatigue, la vigilance et l'erreur humaine. Cela représente un enseignement de sept heures. L'ensemble des cours est réparti en fonction des différents niveaux de progression des élèves. Cet enseignement doit être validé par un examen dont la réussite conditionne, au même titre que les autres modules enseignés, la progression de l'élève.

2.3.2. La formation continue aux facteurs humains s'adresse aux personnels navigants en unités opérationnelles, qui ont déjà une expérience aéronautique. Son but est d'utiliser les connaissances théoriques déjà acquises en école initiale et de les appréhender sous une forme pratique, directement utilisable dans le cockpit. Les équipages apprennent les attitudes pour gérer les ressources humaines.
La forme retenue pour cet enseignement est du type Cockpit Resource Management ou CRM. Ce choix a été déterminé par le fait que les CRM existent depuis maintenant une quinzaine d'années en milieu civil et qu'ils sont bien acceptés par les professionnels de l'aéronautique.

3. CRM POUR C-160 ET C-135FR

Au cours de l'année 1995, l'IMASSA a conçu en collaboration avec l'armée de l'air deux formations "Cockpit Resource Management" au profit des équipages des avions de transport "Transall C-160" et des avions ravitailleurs "C135-FR".

3.1. Identification du besoin

Au sein des avions ravitailleurs C135-FR, une série de problèmes de coordination intra-équipage a entraîné une prise de conscience du personnel navigant sur la nécessité de réfléchir à des solutions pour améliorer la qualité du travail collectif dans le cockpit. Pour le Transall C-160,

l'arrivée du nouveau standard de l'avion s'est caractérisée par une évolution du cockpit avec apparition d'un "glass cockpit" et de systèmes de gestion du vol auxquels les équipages n'étaient pas préparés. Ce saut technologique entraînait des problèmes de définition d'emploi de la machine par des pilotes habitués à un avion d'ancienne génération. Dans un cas comme dans l'autre, les équipages semblaient avoir du mal, dans certaines situations, à trouver des modes de relations homme/homme et homme/machine harmonieux.

Pour répondre à ces questions, l'IMASSA et le bureau Sécurité des Vols de l'armée de l'air ont proposé l'élaboration d'un cours CRM spécifique à chaque aéronef. Ce produit pouvait être réalisé rapidement et constituait une réponse réaliste et pragmatique. Une redéfinition de l'ergonomie des cockpits était impossible, alors qu'une formation à la gestion des ressources du cockpit avait l'avantage de traiter les problèmes tout en élargissant la formation à des aspects facteurs humains plus généraux. La seule résistance de taille à un tel produit était représentée par la spécificité militaire de la population cible et de sa mission. La seule façon de contourner une éventuelle défiance à l'égard d'un concept initialement introduit dans l'aéronautique civile était de convaincre les équipages et le commandement du caractère générique des facteurs humains tout en insistant sur la nécessité absolue de particulariser cette formation au milieu militaire.

Les cours CRM ont connu une évolution importante depuis la fin des années 80 (Pariés, 1994). La première génération de CRM ou Crew Resource Management, s'est inspirée des formations à la gestion des groupes, dispensées aux cadres des grandes entreprises américaines. Les thèmes abordés étaient le "leadership" et les communications au sein du groupe. Les exemples donnés étaient rarement aéronautiques ce qui a eu pour conséquence un succès limité de cet enseignement auprès des personnels navigants. Le cours était source d'intérêt mais pas adapté aux populations concernées.
La deuxième génération de cours s'est caractérisée par deux évolutions : une adaptation à la réalité aéronautique suite à l'échec des premiers cours et un élargissement des thèmes étudiés aux capacités intellectuelles des opérateurs. Mais le principe pédagogique restait de montrer ce qu'il ne fallait pas faire, sans véritablement essayer de comprendre pourquoi des équipages pouvaient se retrouver dans des situations accidentogènes. Les modèles utilisés étaient prescriptifs et peu adaptés à la complexité et à la réalité des situations aéronautiques.
La troisième génération de CRM introduit un changement de philosophie : les relations à la machine et aux situations professionnelles constituent le creuset de la formation. Le CRM devient le Cockpit Resource Management. Il faut apprendre aux personnels navigants à reconnaître les situations dans lesquelles les équipages peuvent se faire piéger et s'enfermer dans des logiques accidentogènes. Il n'y a pas de solutions miracles mais quelques principes forts qui peuvent briser la chaîne d'événements menant à l'accident. Les concepts de conscience de la situation et d'erreur humaine sont à la base de cette génération de CRM apparue au début des années 1990. C'est cette forme la plus élaborée qui a été retenue pour introduire le CRM dans l'armée de l'air.

3.2. Méthodologie de travail

Un groupe de travail a été constitué, composé de représentants d'équipages opérationnels, d'un membre de la division sécurité des vols et des spécialistes "facteurs humains" de l'IMASSA. Les spécifications suivantes ont été retenues pour le CRM :

- durée du cours : deux jours ;
- inter-activité élevée nécessitant des formateurs "personnels navigants" formés à l'animation de groupe ;
- enseignement basé sur des exemples (films vidéos de courte durée, études de cas, débat sur les expériences des participants) ;
- nécessité de mettre en relief un certain nombre de "règles d'or" répondant aux objectifs de formation et adaptées à la pratique quotidienne des équipages.

Un planning a été établi pour arriver à la mise en place en 12 mois d'un produit CRM opérationnel en unité.
Huit séances de travail ont permis de lister et d'approfondir l'ensemble des problèmes rencontrés. Le fait que des équipages des deux types d'avions participaient aux mêmes réunions a été un facteur d'enrichissement non négligeable, puisqu'il a permis de voir la façon dont des problèmes génériques s'exprimaient avec des variations plus ou moins importantes en fonction des particularités des machines et des missions. Rapidement, il est apparu possible de concevoir conjointement deux cours, proches dans le fond, à condition de fournir un effort de particularisation lors des phases de démonstration des problèmes.
Par entretiens itératifs, les principaux thèmes à traiter ont été identifiés : relations inter-humaines au sein des équipages, communication, compréhension des intentions des autres (hommes ou automates), vigilance et fatigue, stress aéronautique, erreur humaine et sécurité du vol.

Une maquette de chacune des deux versions du cours a été testée sur une population restreinte de personnels navigants, puis modifiée en tenant

compte des critiques. Ces sessions expérimentales de CRM ont permis de voir que le produit était bien accepté par les équipages.
La formation des "formateurs" a été réalisée à l'IMASSA. Son objectif était de rendre les personnels volontaires, aptes à diriger une session CRM à une échéance de deux mois, le temps d'assimiler de façon complète le cours. Après un temps de formation axé exclusivement sur la pédagogie, le cours a ensuite été détaillé film par film, transparent par transparent. Enfin, les stagiaires ont répété plusieurs fois les différents chapitres du cours, jouant à tour de rôle les "formateurs" ou les stagiaires. Une assistance en ligne lors de la première session de CRM des "formateurs" est assurée par l'IMASSA.

3.3. Contenu des cours CRM

Le contenu du cours suivant a été adoptée :

Première demi-journée :

- Introduction : présentation du cours et des règles de fonctionnement de la formation ;
- Thème "Équipage" : différents types de leadership du commandant de bord et réactions des coéquipiers (illustré par trois films) ; leadership idéal ; adaptation des équipiers à un leadership excessif ; notion de synergie du groupe.
- Thème "Communication" : définitions ; modèle de communication pouvant expliquer les ambiguïtés malgré l'utilisation du langage opératif (un exemple de dialogue ambigu) ; "pathologies" de la communication en cockpit ; facteurs de perturbations des communications pendant le vol ; règles de protection.

Deuxième demi-journée :

- Thème "Compréhension de la situation" : bases physiologiques (perception visuelle) et psychologiques (cognition) de la compréhension de la situation ; notion de limitation des ressources cognitives et concept de charge de travail mentale.
- Thème "Confiance et doute" : Notion de confiance et de doute vis à vis des informations ou de la source des informations (illustré par quatre films) ; importance du contexte dans la résolution du conflit doute / confiance.

Troisième demi-journée :

- Thème "Stress professionnel" : définitions ; démonstration des effets cognitifs du stress (illustré par un film) ; importance de la reconnaissance du niveau de stress chez soi et chez l'autre ; principes de gestion du stress.
- Thème "Fatigue et Vigilance" : Notion de rythmes biologiques ; vigilance ; jet-lag ; principes de gestion de la vigilance en cockpit.
- Thème : "Erreur humaine" : définitions ; types d'erreurs ; solutions palliatives ; erreur humaine et sécurité systémique.

Quatrième demi-journée :

- "Études de cas" : Les stagiaires se scindent en petits groupes de trois à quatre personnels navigants et analysent deux à trois cas réels avec l'aide des formateurs. Le but est de retrouver les concepts appris dans les demi-journées précédentes. Chaque groupe présente ensuite son analyse aux autres participants.
- "Conclusion" : L'homme comme facteur irremplaçable de fiabilité ; comment mettre en pratique le CRM ? ; notion de retour d'expérience.

3.4. Aspects réglementaires du CRM

Le développement du CRM résulte d'une action de commandement et s'inscrit dans un cadre réglementaire. En conséquence, les modalités pratiques de mise en place du CRM au sein de l'Armée de l'Air ont été définies en concertation avec le commandement :

- Le CRM ne fait l'objet d'aucune évaluation, mais il est obligatoire d'y assister pour avoir un attestation de participation.
- Cette attestation est nécessaire pour obtenir le niveau de qualification professionnelle "commandant de bord".
- Après la formation CRM initiale, les personnels bénéficieront d'une formation de rappel, de courte durée, tous les trois ans.
- Une réunion annuelle entre les responsables de formation CRM des unités opérationnelles, le bureau Sécurité des Vols et les spécialistes de l'IMASSA est chargée de faire le point sur le déroulement de la formation, les problèmes particuliers et les évolutions à envisager.
- L'IMASSA est responsable de la qualité du produit à long terme, ainsi que de son actualisation.

L'ensemble de ces mesures est dicté par des textes réglementaires qui régissent la formation des personnels navigants de l'armée de l'air. Ce cadre réglementaire est important car il permet d'appuyer et de démontrer la volonté du commandement dans la voie qu'il s'est fixé.

3.5. Premiers résultats

Les premières séances CRM ont confirmé l'excellent accueil réservé par les personnels navigants au CRM. Ils reconnaissent l'utilité de la formation et sa forme motivante. Le CRM apparaît comme un lieu d'échange où l'expérience de chacun peut être analysée sous un angle nouveau. Un vocabulaire plus précis est appris et diffuse peu à peu. De ce fait, les échanges informels entre personnels navigants ayant suivi la formation sont plus structurés et surtout dépassionnés. Le retour d'expérience s'en trouve facilité.
L'IMASSA conduit actuellement une évaluation systématique par questionnaire où chaque participant évalue la formation et les

changements induits dans les comportements individuels et collectifs au sol ou en vol.

4. UNE PROCHAINE ÉTAPE : UN CRM POUR AVION D'ARMES

Devant l'intérêt suscité par les deux premiers CRM, le commandement a souhaité qu'un produit spécifique soit développé au profit des équipages de chasseur bombardier Mirage 2000 N et D. La réalisation d'un tel produit constitue un véritable challenge pour deux raisons :

- la notion de travail en équipage n'est pas la même sur avion d'armes que dans un cockpit classique d'avion de transport.
- la mentalité des équipages de combat est différente de celles des équipages de transport. Les notions introduites par les facteurs humains retiennent beaucoup moins l'attention ou sont jugés moins pertinentes en raison d'une culture beaucoup plus individualiste et centrée sur la perfection humaine.

La méthodologie retenue pour la réalisation du CRM est identique à celle des CRM précédents. Il faut cependant noter que de nombreuses campagnes de sensibilisation et d'explication des concepts CRM sont indispensables pour garantir son acceptation. Des entretiens ont été menés avec un grand nombre d'équipages pour identifier avec précision les thèmes à traiter. Enfin, pour inciter et faciliter la participation des stagiaires, l'accent a été mis sur l'ancrage dans la réalité et l'inter-activité avec un nombre plus important de films vidéo.

5 CONCLUSION

L'approche "facteurs humains" est considérée comme une voie porteuse d'espoir en terme de sécurité aérienne. L'armée de l'air française a choisi de faire des efforts substantiels dans cette direction au niveau de sa politique de sécurité des vols. Cette volonté affirmée a pour but d'intégrer l'enseignement des facteurs humains à la formation professionnelle et d'en faire une matière à part entière comme les matières techniques aéronautiques. Cette motivation est justifiée par le désir de donner aux équipages les outils qui leur permettent d'avoir les attitudes et les comportements les plus sûrs pour préserver en toutes circonstances l'efficacité opérationnelle. La formation "facteurs humains" s'effectue en deux temps : théorique en école de pilotage, puis pratique en escadron opérationnel avec l'utilisation de produits de type CRM. Cette formation est basée sur un support scientifique qui garantit sa qualité. La formation aux facteurs humains doit être comprise comme un processus continu tout au long de la carrière des personnels à travers des produits adaptés et évolutifs.

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Understanding the requirement : A review of common problems in training, selection and design.

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A recent review of pilot selection procedures by Diane Damos (1995), one of the foremost specialists in multiple task performance related to aerospace human factors, cast doubt upon the predictive capabilities of pilot selection batteries to identify the specific qualities that identify good pilots in the initial stages of the selection process. In other contributions to the same text many authors poured scorn on the relatively poor quality of psychological tools in selecting out ineffective pilots (Murphy, 1995) or in evaluating pilot's performance with laboratory based tasks (Goeters, 1995). Three conclusions can logically be drawn from this work, presentations at the AGARD Spring Symposium in 1995 on Situational Awareness and other papers in the open literature (Turnbull, 1992). Either the tests applied in selection of pilots are poor in themselves, the understanding of the cognitive demands placed on pilots is poor or the both the tests, understanding of tasks and their application are suspect. Although there have been reports which suggest that predictive validity may, indeed, be declining in tests used in pilot selection (Hunter and Burke, 1994) the problem underpinning the ineffective selection may be inadequate quantitative and qualitative descriptions of the pilot's tasks. Task analysis has been recognised as a major element in effective training and selection of operators (Proctor and Dutta, 1995) and in the design of interfaces for complex systems (Kirwan and Ainsworth, 1992). In terms of Ocham's razor this would, rather surprisingly, suggest that inadequate knowledge of cognitive demands of the task domain are the root of the common problems in selection and training.

Functions of Selection and Training

In reviewing selection and training procedures it is important to be aware of the different functions provided by selection and training. Selection may act as a filter to increase the likelihood of success in basic or advanced training. Or, selection may be used to select for candidates who can master a satisfactory level of performance in a core skill at a faster rate. It is important to remember that rate of learning may be completely unrelated to the final level of performance attained (Proctor and Dutta, 1995). This loose coupling of rate of learning and final level of attainment is important because many authors seem to assume that the factors are by necessity linked. However, most selection systems aim to increase the rate of learning, maximise the quality of learning and achieve the greatest degree of success.

There have been some successes in developing selection procedures like that reported in

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Spinner (1991) and Carretta and Ree (1994) but their success is muted by their generality. The success rate for Spinner's tests were near to 80 percent but the tests were only applied primary flying school. It can be argued that success of the selection program at this early stage is less important than success selecting for performance at later stages because of the very high costs of progressing pilots who fail advanced training. Even when selection schemes are identified which are successful in selecting candidates for primary flight training the same tests can not guarantee success at a more advanced level. The success of Carretta and Ree's (1994) pencil and paper tests is restricted to a specific level of selection and this level of selection may be poorly related to the long-term development of the pilot in advanced training. Some skills or aptitudes, like psycho-motor skills are important throughout the operational life of a pilot but they are perhaps not as central to optimum performance in a fast-jet strike aircraft where planning, scheduling and decision making take on a greater importance. Indeed, the some of the early selection procedures may eliminate candidates who could be become very effective pilots with extended basic training because of the failure to identify core skills required for the later phases of pilot training. Perceptual-motor skills can be very well developed by extended training but the evidence that the same is true for the higher-level cognitive abilities is questionable. In simple terms, the higher level cognitive skills may hit an internal limit which is more deleterious for final performance because they can not be developed as effectively through training in the way that psycho-motor skills can.

In many ways the problems facing developers of selection batteries are the same ones facing those developing training programs but they are more acute. Trainers can often adopt a more pragmatic approach to selection in later phases of training because the candidates can be submitted to part-task simulation exercises which draw upon the poorly quantified attributes that contribute to the development of an effective pilot. A more pragmatic approach is supported by research on skills which suggests that part-task training must take account of context and specifically identifies problems with simulations which provide inadequate cues when related to the real operating environment (Proctor and Dutta, 1995).

Skills : A Moving Target

Developers of selection procedures are essentially dealing with a dynamic system in which skills are developing and changing. The changing nature of skills during development is accepted by most major models of skilled performance which recognise a shift in the cognitive demands of skills during different phases of acquisition. Fitt's *Phases of Acquisition Model* (Fitts, 1964; Fitts, 1990; Fitts and Posner, 1967), Anderson's (Anderson, 1982,1983) *Framework for Cognitive Skill Acquisition,* or Rasmussen's *Modes of Performance Model* (Rasmussen, 1983, 1986) may have differences of opinion about the specific details but they come to agreement on the phased nature of skill development. In operational terms it may be difficult to establish exactly when a skill progresses from one phase to another but that does not disqualify the taxonomic approach offered by models of skill acquisition. The transitional nature of skill development suggests that test developers may be trying to estimate a skill which is not realised in the novice and can only be tested after a certain amount of basic training.

Few would argue that many skills change from an intensive occupation involving high demands on specific intellectual/cognitive capacities and develop into an automatic effortless process in many cases. However, there appears to be very little research in aviation psychology examining and classifying the types of changes or the cognitive capacities which are critical to the different phases of the development of skilled performance. The absence of this research is compounded by the recognition, in more sophisticated models of skill development, that different skills are required for different levels of skilled performance (Ackermann, 1988). Accepting that skilled behaviours and the abilities they depend upon vary across time one must accept that training plans and selection procedures must change over time to focus on the development of the appropriate skills required at that phase in performance. However, many analyses of pilot selection procedures seem implicitly to expect that the same measures will be predictive over the complete training period from basic to advanced levels. For example, a study by Carretta and Ree (1996) examined many different variables in an attempt to identify factors that might predict good situational awareness in pilots and found that years of service on the aircraft type were the major predictor. This type of finding suggests that something does indeed develop over time and that is likely to be implicit domain knowledge which is poorly articulated. This type of unconscious accretion of knowledge is another well established property of skilled behaviour (Proctor and Dutta, 1995). It is clearly possible that certain core characteristics of an individual may make them more or less suitable for advanced pilot training but it seems to be extremely unlikely given the diversity of tasks a pilot must accomplish in civil or military aviation.

It is clearly possible that measures that have been used to select the pilot population generate the expectation that those same measures are adequate predictors of performance and one is left with a circular argument supporting the use of specific tests applied to early selection. The circularity of this argument is evident in research which unsurprisingly finds that jet pilots are better at a series of tests than college students when the tests are very similar to tests used in selection procedures (Temme, Still, and Fatcheric, 1995).

Focused Training

Training can designed to achieve rapid development of skills or to slowly build skilled performance to required performance levels in specific areas. Implicitly selection assumes that individuals can be measured and candidates chosen with the appropriate attributes which can be developed by training. Even though aptitudes can measured and examined at different stages in the selection process one needs to determine which aptitudes can be developed by training and which are relatively immune to training. Even if an aptitude can be further developed by training one still needs to assess how critical the skill is to overall task performance and how much effort must be expended in the development of the skill. Ultimately there must be a trade-off of skill value and costs in terms of training, if appropriate and possible.

Although selection and training require a knowledge of the task(s), and the skills that underpin the performance, training procedures can be much more pragmatic in using part-task training based on relatively crude analyses and still be successful (Proctor and Dutta, 1995).

Selection batteries often require a much more sophisticated analysis to identify the cognitive skills that are required to accomplish a task as a particular level of competence. Greater precision in the qualitative and quantitative task descriptions should increase the predictive validity of tests used in selection and the efficacy of training procedures by revealing the underlying cognitive skills that pilots rely on. Poor selection can result in problems in training but it may be difficult to distinguish poor selection procedures from poor training because of their common root in the poor understanding of the critical task requirements. The natural tendency of low-ability pilots to drop-out, in the natural run of events, as training progresses may in fact explain the tendency for pilots to improve performance on key skills like situation awareness (Carretta and Ree, 1996).

It can be argued that the basic problem lies in a poor understanding of the task domain because this is clearly the most parsimonious explanation of problems in selection of pilots, training of pilots and design/integration of equipment into the cockpit. This poor understanding is highly visible in areas like situation awareness, decision making, response to emergencies and this suggests that knowledge is most limited with respect to high level cognitive skills.

Changing Demands and Constant Measures

Damos (1995) astutely noted that pilot selection batteries had changed little in fifty years with the emphasis on intelligence tests, psychomotor/perceptual skills tests and some measures of personal qualities. These types of selection technique are fairly good at predicting early success in flying training but estimates indicate the variance accounted for at advanced training are a meagre, at most 25% (Beaty, 1995). The performance, in terms of incremental validity, of batteries presented at this conference are not significantly different from those reviewed by Damos (1995) and considered by Beaty (1995).

This emphasis on intelligence and personality seems all the more surprising when one considers that many authors examining complex supervisory control systems in industrial environments have placed great stress on the effects of changing technology and the need to support the performance of the operator through more effective cognitive modelling techniques which in turn rely on more detailed qualitative and quantitative analyses of behaviour. Again the emphasis is weighted towards skills like task-management, scheduling, planning, problem-solving which are emergent properties of cognition and experience on the task. The changes in the use of technology in aerospace have been as or more dramatic than those taking place in industrial control systems and the parallels have been recognized by those reviewing aerospace accidents and incidents (Beaty, 1995). Much of the effort in aerospace appears to have focused on increasing the bandwidth of information transfer between man and machine at a time when the cognitive demands are increasing through increasing use of single-seat designs in military aircraft and disappearance of the flight engineer in civil cockpits.

There have been many changes in cockpit systems in the last thirty years, the normal lifetime of an aircraft, and these are covered in detail by textbooks like Weiner and Nagel's (1988) book of edited contributions. These changes have taken place within the context of other changes like reductions in crew size and growing concerns about effective crew

operation characterized by textbooks like Weiner, Kanki and Helmreich's (1991) Cockpit Resource Management. Crew size and the distribution of tasks between man and machine has become a key area in recent years in both civil and military jets. It is clear that this is an area where detailed task-analysis can have a major effect on the quality of the interface (Kirwan and Ainsworth, 1992) but only if the task analyses used are sufficiently detailed in qualitative and quantitative terms. These dramatic shifts in the perspective taken by literature implicitly recognise the changing demands placed upon pilots by new systems but these shifts has largely been ignored in selection and training practice. The absence of change in the selection batteries might suggest that, irrespective of their original validity, they are now seriously out of step with the cognitive demands of new technology, a point indirectly made by Hunter and Burke (1994).

It seems that the current intelligence and personality tests provide very poor predictive validity for advanced training and this in turn would suggest that they have little more than face validity which in practical terms is useless. The problem with general intelligence and personality tests could be broadly similar to the difficulties encountered in the application of such tests in neuropsychological assessment of brain injury. General tests can not be used to delineate the specific nature of deficits after brain injury because they do not measure a narrow functional characteristic. In simple terms general intelligence tests provide general measures of arithmetic, linguistic, visuo-spatial and problem solving abilities and these skills rely on large areas of brain tissue. Specific sub-components of these skills may be lost through brain injury and disturb overall performance of the higher level skills. To identify the sub-component that is lost requires a much more specific type of test directly aimed at assessing the sub-component level of skills. In a similar vein the more capable pilots may be a group in possession of specific sub-component skills that are more closely related to performance at the end of training. General tests may not adequately measure with sufficient precision the sub-component skills that make the difference between a good and an excellent pilot. The basic problem may be that the tests applied in selection do not meet the necessary types of validity.

Validity of Tests

The main types of test validity are content, criterion and construct validity (Kaplan and Saccuzzo, 1993).

Content validity refers to the need for a test to provide an adequate representation of the conceptual domain it is intended to cover. Clearly intelligence tests are not aimed at identifying the next generation of fighter pilots even though the next generation may have to possess a certain degree of intelligence to master the task domain they operate within. It is clearly important to be relatively quick witted when flying fast aircraft at low altitude. Examination of expert decision making suggests that slow, deliberate planning or extensive preparation is a key characteristic of quality decision making and not speed (Proctor and Dutta , 1995). If effective decision making is a key element of advanced piloting then the content-related validity of intelligence tests in aircrew selection is very weak. It seems unlikely that progress will be made in the training of effective decision making when training manuals (Green, Muir, James, Gradwell and Green, 1996) and CRM courses emphasize the social psychological problems that can undermine effective decision making.

It can be argued that pilots need a more effective briefing on the individual biases and heuristics that operate in thinking and naturalistic decision making (Huey and Wickens, 1993; Klein, 1993). A review of recent accidents in the civil arena, reported in the national press, in the last five years, indicates that many of the flawed decisions contributing to the development of accidents could be identified with faulty information processing strategies found in a single individual. There is no substantive evidence that social pyschological palliatives, aimed at promoting more effective decision making, would have reversed the outcomes. It seems that more effective training and selection of personnel with respect to tasks is required. This in turn suggests a more effective understanding of the roles of the pilot and crew is required.

The current evidence from crashes and inquiries with respect to crashes suggests that faulty decision making is a major contributory factor in some accidents and a key factor exacerbating the consequences (Beaty, 1995). For example, the Dutch Aviation Transport Board has criticised the decision of the El Al 747 pilot who crashed into a block of flats outside Amsterdam and the training the pilot's were given in assessing risks at take-off and responding to major system failures (Pope, 1994a). A Turkish flight crashed during landing in poor weather because the ex-military pilot failed to take advice from air traffic control with regard to the hazardous conditions at the airport (Pope, 1994b). Faulty decision making may also contribute to loss of friendly aircraft (Bellamy, 1994). In a similar vein the tests of personality and the training provided do not seem to prevent pilots discussing irrelevant matters below 10,000 feet on an approach to an airport (Cockburn, 1994) or incorrectly assessing the amount of runway left after landing (Wolmar, 1994). If anything casts doubt on the effectiveness of pilot training and selection it must be the increasingly frequent recognition of pilot error as a major contributory factor in accidents. That pilot error is recognised as the major contributory factor in many civil and military crashes begs the question with regard to what exactly is going wrong in selection and training. The most parsimonious answer that would cover problems in design of equipment, pilot selection and pilot training, is a poor qualitative and quantitative understanding of the pilot's overall task.

Tests have *criterion-related validity* if they are adequate for the measurement purpose for which they are used. The forecasting function of tests in selection is a type of criterion validity which is known as *predictive validity*. The evidence cited by Damos (1995) suggests that the battery of tests used by the U.S. Air Force in undergraduate pilot training has very low predictive validity with correlations of the order of no more than 0.4 with pilot performance characteristics. A simple low cost way of trying to reduce the cost of poor selection is to use tests that have *concurrent validity*. Concurrent validity assesses the simultaneous relationship between the test and the criterion performance. There are, however, problems with this way of developing tests because the successful set of pilots may not adequately represent the qualities that should be used at selection. In simple terms the similarities in the final population of pilots who reach active status may not adequately reflect the qualities that make a good pilot but may more accurately reflect the selection process used. It is highly probable that ineffective selection procedures may actually produce

spurious and artefactual predictors of pilot performance.

There is a great deal more to be learned from examining the qualities of the failures (Proctor and Dutta, 1995) because they more adequately provide the relevant contrasts to help identify key features of the very good pilots. It must be noted that there are studies which seem to indicate that little can be gained from examining those failing to make the grade (Carretta, 1992) but it might be argued that this can equally be a criticism of the tests or the statistical methods applied. It is hardly surprising that tests which are very close approximations to the final task are good predictors of performance. Tests may indirectly measure an aptitude which is critical in the performance of the aviator's role but the specific aptitude measured may be non-linearly related to performance across the lower end of the range beyond the cut-off. Most correlational statistics require that data are linear, they are susceptible to range effects and they give no support to a causal relationship even if they are significant. In simple terms the criterion applied in selection and the effect on predictive validity is clearly significant in that here is a high probability of the result being mis-leading.

Critically tests applied in selection must have *construct validity*. Establishing construct validity means assembling evidence about what the tests actually mean. It is here that process of constructing test batteries for most occupational selection processes fall down because the subject-matter experts fail to agree upon the key characteristics which are required to achieve the required performance. It is surprising that a great deal of effort seems to be invested in considering what makes a good pilot. It would clearly be equally beneficial to know what makes a poor pilot but so little research seems to be directed at what makes pilots fail to achieve the goals set for them in later phases of training and selection. This is clearly an area where advances can be made and it is the Achilles heel of current selection batteries.

The important point to recognise is that the occupational role of a pilot and the problems in their selection are not so dissimilar to the problems in selection in many other occupations. The surprising thing is that so much money seems to have provided so little gain in terms of understanding what makes a good pilot. It can be argued that the poor comprehension of the pilots role is reversible and with it the problems of pilot selection and training. Equally important the design issues relating to equipment used in the cockpit could be substantially improved with a well focused research project aimed at understanding the cognitive demands of the cockpit by detailed task analysis.

Tactical Cockpits - A False Dawn

The creation of advanced cockpits in the mould suggested by some authors (Adam, 1992) may accelerate the acquisition of information but still fail to significantly improve pilot performance. The same reasons may lie behind the lack of significant improvement with new technology and the problems revealed in using general intelligence tests as measures for the selection of pilots. It may simply be the focus on quick wittedness and speed of processing which does not necessarily seem to be a characteristic feature of expert performance (Proctor and Dutta, 1995). This focus on elemental skills is all the more surprising when reviews of new technology applications in the cockpit like that of Adam's (1992) clearly

identify situation awareness and higher order cognitive skills, like those involved in planning, as instrumental in different types of operation. The importance of higher order cognitive skills has been highlighted in reviews presented on Workload Transition (Huey and Wickens, 1993) and in reviews of workload management (Adams, Tenney, Pew, 1991). Indeed, rapid responses by experts may be poorer than those made by novices because experience can exaggerate biases in thinking (Huey and Wickens, 1993) while accelerating the speed of response. Automaticity is certainly a feature of many skilled activities (Proctor and Dutta, 1995). Some accept that pilots over learn certain tasks they carry out in the cockpit but they are equally at pains to point out the dangers of rigidity in the pilot's behavioural repetoire, particularly if latent design errors exist within the cockpit (Beaty, 1995). Critical appreciation of information quality and validity from different systems and crew members is a key element of crew/cockpit resource management training, which in turn builds upon the knowledge of outcomes related to poor situational awareness.

Elemental components of skills can clearly play a part in increasing the probability of a more advanced skill levels or attainment after training. Elemental skills can indirectly increase the time available to formulate a more effective plan, and maintain more effective situation awareness, but it is not directly associated with higher cognitive functions such as planning, problem solving and effective decision making. Analysis of skilled behaviour suggest the greatest gains in performance during training are to be found in response selection processes which may in turn be related to meta-cognitive skills. It seems increasingly likely that problem solving skills and analytical skills which play a part in acquiring a more effective understanding of the problem domain vary across a population. Thus, it may be these self-reflexive skills that foster more effective performance after training and they may increase the rate of skill acquisition. There is anecdotal evidence that more effective learning performance may be achieved by those who are more aware of their own performance and able to modify their actions to increase the effectiveness.

Understanding the Task

If one accepts that there is a poor understanding of the cognitive demands on the pilots then this should visible as problems in three areas of work related to technology development. First, in protracted development and integration of new sub-systems within current cockpit designs. Second, in development of new cockpit designs. Third, problems should not be apparent or adequately highlighted in pre-feasibility studies where trade-offs between different sub-system designs and modes of operation are considered. These problems in developing new equipment, and the poor understanding of task integration it represents, suggest new equipment will place unknown demands on the future aviators. If a good understanding of the current tasks can be achieved and new equipment is investigated, to validate a prediction based upon a cognitive model of its operation, the present gaps can be closed. Once again, the first step is a thorough analysis of the pilot's task and an intensive case based analysis to validate the cognitive models of the pilot's performance. This in turn can be developed into a training program. This type of approach
has already shown some success (Irving, Polson and Irving, 1994) but it required a very detailed understanding of the task examined and creation of a taxonomy of sub-tasks.

The profile of the current problems should be highest in the design, development and deployment of systems acting as aids to the pilot as these integrate functions across tasks. This need for integration means that errors in judgement about the task demands on pilots should be cumulative and this would appear in integrated task behaviours, such as situation awareness. For example, tactical information sharing systems and mission planning systems would be particularly sensitive to errors in judgement about cognitive demands. The multi-tasking nature of the modern single-seat cockpit clearly requires the integration of navigation, planning, weapon and control systems which would be most susceptible to the inaccurate perception of cognitive demands on the pilot. However, failures in these operations are not always reflected in immediate performance but extend across time as errors in situational awareness and decision making. Delayed problems in situation awareness have been identified with speech systems (Cook, Cranmer, Finan, Sapeluk and Milton, 1996) and in multi-modal information delivery (Cook and Elder, 1996).

Reviews of accidents and incidents suggest that cognitive errors and failures are more likely to be reflected in *unexpected* catastrophic events or infrequently degraded performance (c.f. Woods, Johannesen, Cook and Sarter, 1994). In simple terms, problem in assessing cognitive demands would introduce latent errors into design of sub-systems which will contribute to poor performance. Poor performance can easily be missed because the kinds of degradation may not be revealed by a superficial analysis of more regular performance measures. For example, speed and accuracy measures that produce an overall level of acceptable level of average performance may conceal specific clustering of failures around particular contextual features. A good example of this type of problem exists in multi-modal information systems where it is apparent that problems exist in switching attention between modalities (Cook and Elder, 1996). More recent work has revealed that these problems can occur at relatively low-levels of workload with speech-based systems, which have been explored, proposed and used in the cockpit. The memory-failures which occur with complex control systems which would present problems for situational awareness and it is specifically this type of problem that has been highlighted as a contributory factor in flawed human performance with complex systems (Reason,).

A great deal of research in product development and in pilot selection focuses on measures of performance that reflect immediate failures or speed of processing a trend that is remarkably similar to the measures taken in early phases of pilot selection. Consequently research overlooks the more subtle errors that degrade performance over time because they aren't directly observable and are often attributable to higher order meta-cognitive skills.

Interactions between tasks can be equally disruptive at macro and micro levels (c.f. Wickens, 1989). However, the pilot may be more sensitive to and aware of the consequences when interactions take place at the micro level and this supports the well established emphasis on speed of processing. The execution of one further task which is mission critical but executed in parallel with a safety critical task may lead to catastrophic failures in deployment of equipment. This type of negative interaction is particularly likely if the tasks share common processing resources.

Thus, in targeting and operating the control surfaces of the aircraft there are common requirements for spatial processing which may interact destructively causing deterioration in one or both tasks if they are executed simultaneously. The tracking tasks need not be constantly antagonistic and it may actually degrade performance more if the relationship between the tasks changes over time.

The low-level flight favoured by some air forces would make these negative interactions between spatial tasks potentially disastrous, generating high attrition rates and greater rates of mission failure. More importantly, processing conflicts such as these will routinely arise in a single-seat cockpit selected in future aircraft and for that reason they have attracted the greatest degree of interest from those seeking to introduce more sophisticated avionics as the solution to the problem. Technology may be a very weak solution if the qualities of the new equipments are not married to the skills and capabilities of the pilot. If one cannot guarantee the qualities of the pilot are useful in the task then one may face major difficulties in creating appropriate equipment. There is clearly a circularity in the dependency with selection, training and design intimately linked. The crash of one of the first Saab Viggens in service was directly linked to a mis-match between the control demands imposed on the pilot. This failure is all the more surprising when one realises that psycho-motor tests batteries are well established in selection procedures and control surface management training are key elements of pilot development. If our understanding of knowledge in a well-explored aspect of human performance is so fragile it is perhaps surprising that accidents have not increased dramatically in recent years.

Problems related to time-sharing

Time-sharing across micro-tasks may be a more visibly demanding task to the pilot because of the temporal imperative. However, more distant interactions may occur in macro tasks if operators fail to process appropriate information and situational awareness deteriorates as information is forgotten or cannot be retrieved. It is more likely that these more distant interactions are imperfectly monitored by the individual pilots and there opinions may be a poor indicator of the skills required to achieve an adequate performance.

A number of the critical features that determine the quality of processing and quality of recall are external to the pilot. For example, the rate at which events occur and the rate at which critical values change on the different channels of information monitored by the pilot, which jointly determine the time available for consolidating the processing of information. This clearly suggests that the intellectual qualities of the pilot may play a role in achieving an acceptable level of performance because speed of processing assessed by IQ tests will correlate weakly with pilot performance. However, the scheduling, monitoring, prediction and planning elements of the pilots role can lead to more or less adequate management of the task over time and it is recognised as a key part of skilled behaviour (Proctor and Dutta, 1995). In effect good pilots need not be quick witted but they must use the time available wisely. This in turn would help to explain why general intelligence tests are very poor predictors of future performance on advanced training. Speed of processing information from visuo-spatial or verbal sources is quite adequately measured by general intelligence tests but the meta-cognitive organisational abilities are not. It is clearly important to attempt to measure the part

played by meta-tasks i.e. scheduling and meta-cognitive structuring of problem-solving in the pilots role to determine if these are effective measures for use in selection.

This interpretation of the current problems in selection and recruitment test batteries has some support from the problems identified by Damos (1995). First, attention switching should still be a reasonable predictor of future pilot performance because intelligent scheduling of tasks will not overcome a slow and error-prone changeover from one task to another. That attention switching tasks have a moderate predictive validity is one of the results that Damos(1995) reports. Second, it might explain the reason why simply counting the number and not the type of concurrent tasks is a reasonable predictor of workload. Third, meta-cognitive abilities are precisely the type of high level ability that is missing from current test batteries. It is important to remember that meta-cognitive strategies may play a part in the learning of new information because these abilities help to forge new schemas for linking external events to appropriate actions. Thus, meta-cognitive strategies would impact on the rate of training and the final performance one might expect from pilots.

If the appreciation of the pilots role with current weapon systems is poor then the speculation concerning the demands of future cockpits is even more likely to be flawed. In the single-seat operation greater emphasis is required to select pilot's with the right stuff because of the new roles acquired by the pilot as a result of the absence of the navigator/weapons officer on the previous generation of aircraft. The key question is how to attack the problem of understanding the pilot's roles, for in reality, there are many.

Tasks, Aptitudes, and Selection

Two popular approaches to the development of selection tests are based on the Cognitive Correlates Approach (Fleishman and Quaintance, 1984) and the Cognitive components approach (Ackerman and Kyollen, 1991).

The Cognitive Correlates Approach examines the inter-relationships between aptitudes, abilities and task performance. This approach could be applied to high and low ability pilots to determine which types of test were significantly correlated with pilot ability. The basic problem with this technique is the statistical method used to isolate related abilities. Correlations are weak predictors in restricted ranges and even when found correlations can be related through an intervening variables. This is particularly problematic with skilled behaviour because there are often many different interpretations that could be put upon the changes in performance related to individual differences.

A good example of the dissociation of skills within a task is found in neuropsychological terms where one finds the involvement of frontal lobes and parietal lobes of the brain in some visuo-spatial problems. In general terms these areas of the brain are concerned with plan formulation and perceptual analysis. Subjects may have superior performance on visuo-spatial problems because of faster perceptual processing or as a result of faster plan formulation. Such visuo-spatial tests may correlate well with superior pilot's abilities and appear to have predictive validity in a sample population. Superior pilots may actually have more effective planning abilities and the application of the visuo-spatial tests to a

heterogeneous group of pilots with good perceptual skills but mixed abilities in plan formulation may prove to have poor predictive validity. The problem of identifying the underlying skills has been noted by Carroll (1989) who has suggested the correlates are of little use because the aspect of the general tests related to the experimental tasks cannot be determined.

The cognitive correlates approach can be successful when there is a good understanding of the task and its sub-components. One method for achieving this is through the use of neuropsychological evidence like ERPs, PET scans, NMR scans and CBF studies which indicate the commonalty of the underlying brain structures involved. The cognitive correlates approach to identification of aptitudes may not successfully isolate higher order cognitive functions but it may help to establish the role played by attention in multi-task performance.

The alternative approach to aptitude identification is to start from an analysis of the component processing stages and then to estimate performance at each of the stages. This is termed the **Cognitive components approach** (Ackerman and Kyollen, 1991) which was originally developed by Robert Sternberg (1970) and called the **componential metatheory**. This type of approach could be driven with data from task analysis of pilot performance.

Sternberg's (1979) theory of mental abilities is significant in identifying both vertical and horizontal components to task performance with four categorical levels of task description. These units of task description are :-

1) Composite Tasks - are the complete tasks.

2) Subtasks - arrived at by decomposition.

3) Information Processing Components - elemental processing of information.

4) Task scheduling/control - determined by meta-components.

It can be argued that most measures applied in selection of pilots are adequate for identifying the first three units of description but not the last level of task description. It is possible that the tasks used in selection batteries may not be strongly related to actual tasks that the pilots will do after training. These possibilities can only be adequately addressed by empirical evidence and not by conjecture which once again requires detailed task-analysis of pilot performance.

A general criticism of this componential approach is the need to integrate information processing skills vertically and horizontally which may not be easily identified by the analytical techniques used in the intellectual dissection of tasks. Language is a skilled activity that requires a range of elemental processing abilities within modalities and integration of information across at least two modalities. These horizontally arrayed abilities require further integration. In neuropsychological terms it is clear that the elemental processing abilities at input, output and intermediate stages require integration but this integration takes place vertically. The closely integrated nature of the processing makes language susceptible to failures in processing on a local level but some of the greatest deficits in language processing appear when the integrative nature of the processing is disrupted. These disruptions can be associated with planning/execution problems or with

problems in the control of attention which are related to the skills that pilots may require.

Complex skilled abilities like those executed by pilots essentially may be similar to language at a superficial level and equally susceptible to disruption as a result of poor vertical or horizontal integration. This integrative capability may be an emergent property which appears in certain individuals as a result of training and it may be measures of related abilities that more accurately predict future performance at the entry level selection procedures. This analysis suggests that attention and its deployment in selective, vigilance, and divided attention tasks should be reasonable predictors of pilot performance. To some extent this is supported by reports used in the cognitive psychology literature and by the observations of Damos (1995).

General Human Information Processing

From the previous discussion of general intelligence tests one might presume that an examination of general human information processing was irrelevant to the analysis of skills in selection and recruitment. However, it can be argued that there are features of the general model of human information processing that can be usefully applied in considering the qualities of a good pilot but only if one takes account other factors like the neuropsychological evidence available on division of function across the central nervous system.

Problems in Modelling Multiple Task Performance

To model any system with either a mathematical or statistical model one needs to know or understand the processes and the factors that determine the performance in the relevant domain. There are models that attempt to provide a taxonomic analysis of behaviour over time considering both overt and covert processes required to support the behaviours identified. There have been attempts to increase the sophistication of the multi-task and workload models by quantifying the degree of interaction that takes place between different tasks and the processing demands they represent. The major problem that exists in many of these models is the uni-dimensionality of the representation the models afford, which fail to take account of variations in the populations who will be called upon to accomplish the tasks. Thus, single figures are often applied to negative and positive interactions between tasks as if they represented the performance of an average operator.

Even an average operator's performance can vary dramatically over time and some small degree of change in the temporal structure of the task can result in dramatic changes in performance. Is this perhaps the reason why it has proven difficult to avoid the high frequency of crashes at take-off and landing in civil airlines or the higher losses during high demand low level fast-jet operation. For both civil airline pilots and military jet-pilots there appear to be distinct patterns of failure which cluster around times of high demand which have been apparent for many years. The inability to make any significant impact on the distribution of crashed aircraft within the flight envelope is equally damming. When put alongside the criticisms made by pilots and flight safety bodies with regard to poor training for the inevitable mishap it is clear that our understanding of the pilot's tasks is poor.

If one accepts that workload models are failing

to provide an adequate model one might explain the inadequacy in a number of ways. It could be suggested that the task descriptions used are superficial and fail to capture the relevant or *real* parameters underlying cognitive demand. In simple terms the models do not model cognition but describe it. This type of criticism has been accepted in user-modelling of cognitive processes in HCI which in many ways represents a much more sophisticated approach than that applied in modelling cockpit tasks. A second alternative is that models of multi-tasking are adequate for many purposes but lack some key parameter which introduces a non-linearity into certain types of performance. This would explain the spectacular failure of workload models in the region of moderate demand and it might explain the problems in defining a point of failure, where performance degrades catastrophically. Underlying these domain specific problems may be a very limited database on the demands introduced by different tasks in the cockpit.

That a problems exists in accurately modelling and predicting mult-task performance in the cockpit cannot be denied. It is equally difficult to ignore the essential fact that the nature of our ignorance remains open to speculation and in the worst possible case it may represent a complete inability to describe and model the majority of the relevant factors controlling overall performance.

Improving Models of Multiple Task Performance

If one considers any list of key elements in skilled behaviour one can easily pull together a number of improvements in the current knowledge base with regard to modelling mult-task behaviour which might in turn improve the design of equipment, the selection of air crew and the training of the air crew. The cornerstone of these improvements is the understanding of the tasks accomplished in the cockpit. Most textbooks on skill acquisition and skilled performance place an adequate task analysis at the top of the requirements in any training program or selection process (Proctor and Dutta, 1995).

1) Learning can often be improved by increasing the salience of key elements of performance, the stimulus or the response. A thorough analysis of performance would help identify key elements of performance at different stages in training. If this were already available then training programs for crash procedures in civil aircraft and complex manoeuvres in military fast-jet operations would be decreasing in number with each year of service.

2) The context in which learning takes place affects the nature of learning taking place and an understanding of the tasks should help to isolate the key elements of environment required to train performance in the sub-tasks. If the key factors in simulator training were adequately identified then expensive and dangerous operational flying might be reduced and supplemented with extensive simulator training. Relatively low quality classroom training is one of the factors which has been suggested as a contributory factor in the Kegworth 737-400 crash (Beaty, 1995).

3) Stimulus features are coded with regard to the tasks for which they are used and analysis of the environmental features should clearly identify the key elements which guide behaviour. Once again training could be focused on part-task training to develop the necessary skills at the appropriate point in the

training schedule and air crew could be effectively selected for natural aptitude in the appropriate areas. Training has been cited as a contributory cause or an exacerbating factor in many civil accidents (Pope, 1994; Cockburn, 1994; Beaty, 1995).

4) The conditions promoting practice must be handled carefully to ensure transfer of learning and this could be developed progressively to accommodate development of different skills at different levels of training. The current appreciation of simulator training seems to revolve around a pragmatic approach to simulator based training and not to be sharply focused on the development of advanced training of cognitive skills for critical points in the flight.

5) Automaticity of performance can be achieved by consistent practice conditions but variety of conditions is necessary to achieve a required level of automaticity with regard to a number of situations. Again an analysis of operational activity should reveal a taxonomy of flight context in which the pilot must function effectively and this information, combined with a cognitive task analysis, should guide the quantity and quality of different skills in training.

6) There are degrees of automaticity in many tasks, apparent at different levels of skilled behaviour, and training must accommodate the development of automaticity in appropriate tasks at different stages in training. It is known that individual differences often play a role in performance in both the early and the late phases of skill acquisition but this topic is found only sparsely in aviation psychology literature. It seems that a static model of air crew suitability is used and little attention is paid to the type of dynamics suggested by models of skill acquisition (c.f. Ackerman, 1988; Marshalek, Lohman, and Snow, 1983).

7) Most acquired skills show good long-term retention. Good long-term retention of cognitive tasks requires effective schematic learning in the first instance. Effective schematic learning can be enhanced by a clearer understanding of the relationships between external stimuli, internal response selection/decision making, behaviour and outcomes.

A major difficulty in applying these general characteristics of skilled behaviour is the intervening role of attention in many skilled activities. No single model of attention adequately encompasses the findings from selective, focused, divided and sustained attention tasks. The degree of attention required by tasks varies as a function of the automaticity with which the task is carried out. Time-sharing seems to be a skilled activity in itself which can be developed through training and this can in turn be a factor in effective dual-task performance.

The micro- and the macro- temporal structure of events can, however, unravel performance by placing high intermittent demands on performance that defeat training in dual-task performance and the automaticity afforded by extensive practice. This uncertainty with respect to temporal factors is compounded by the uncertainty relating to the effects of sustained attention in high demand tasks. There are simply an absence of experimental investigations exploring the high demand, multi-modal environment in the laboratory that could be used to adequately quantify the interaction between level of demand, modality and temporal probability in sustained attention tasks. Even if such an analysis was available it

would be impossible to compare or contrast this with an adequate database on actual pilot performance.

The kind of assertions proposed in this section are based upon trends recognised in modern textbooks on skill acquisition where the themes of training, selection and design share the common theme of task analysis. It is current reliance on task descriptions and the poor quality of the current task analysis that reveals the common problem which is inescapable in the reviews of problems associated with the glass cockpit (Learmount, 1996) and other flight management systems (Sarter and Woods, 1992).

Summary and Conclusions

There are problems in selection and training of pilots. There are also problems in the design of new equipment in the cockpit and new cockpits. All these problems may be parsimoniously attributed to a common problem of a relatively poor understanding the pilots tasks.

The problem with defining requirements for equipment and the difficulties in appreciating the pilots tasks are not unlike those identified in the development of human-computer interfaces. The development of new equipment by aerospace manufacturers has already moved strongly towards the user-centred design philosophy operated in the development of human-computer and man-machine interfaces. The user-centred approaches have been adopted as a standard by the computer industry but they can still fail if they rely on acceptance and not performance tests. There have also been significant attempts to improve the methodologies applied to interface design. The spectacular lack of success with both user-centred design and new methodologies indicates a more focused cognitive and task based analysis of the pilots role is required.

While not discarding the pilot's viewpoint it is important to recognise the difficulties many experienced operators have in recalling their behaviour and thoughts in skilled activities. Many authors recognise that skilled activities in general and pilot's activities in particular may gradually become more automatic as training progresses. The development of automaticity in the accomplishment of many tasks would in turn indicate the reliance on implicit memories to identify key elements of the current range of tasks which are then used to guide decision making and selection of behaviour. This would suggest an extended horizontal exploration of the pilot's tasks across a range of combined tasks at different points in the mission to be able to summarise the key qualities of good pilots.

The basic skills and psychological literature has only very recently received an extremely critical review by Flach (1996) who has cast doubt upon the value of tasks, abilities and performance measures taken from laboratory research and applied in an analysis of real-world problems. In this review it has been suggested that much can be learned from this same literature but it needs a much closer analysis of the task domain to apply the knowledge currently available. This same need is identified by Flach (1996) but he has failed to recognise that a general critique of psychological and skills literature is premature if one can not be sure of the tasks one is actually describing in qualitative and quantitative terms. Many authors like Wickens (1984, 1992), Stokes, Wickens and Kite (1990), Adams, Tenney, and Pew (1991),

Woods, Johannesen, Cook and Sarter (1994), Satchell (1993) and the authors contributing to Diane Damos's (1991) collection of papers, draw heavily from the mainstream psychological and skills literature to explain phenomena encountered in the cockpit. More importantly careful analyses of systems, like the flight management system using task-oriented analyses have successfully helped to reveal problems experienced in laboratory tests and experienced by trained/operational pilots (Irving, Polson and Irving, 1994). Interestingly, Irving, Polson and Irving used the task-analysis to successfully guide the training of subjects in their experimental tests and one can imagine the same process can be applied to all avionics systems in both military and civil cockpits.

This recent evidence reinforces the original claims that the current knowledge of the cockpit tasks needs to be expanded substantially in qualitative and quantitative terms. Only with a greater corpus of information can one expect to solve the common problem in selection and training of pilots which directly impinges on the design process. It is important to stress that this requires more than simple mean attributes of pilots but estimates of variance to effectively model the cognitive demands across different phases of flight, during emergency procedures and different situational demands.

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PERFORMANCE AND WORKLOAD MEASUREMENT IN SIMULATION-BASED TRAINING

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SUMMARY

Experiments were conducted to determine the utility of measures of skill acquisition in simulator-based training. Objective performance measures were supplemented by workload measures, to permit assessment of possible changes in demand for mental resources during task learning. In the two experiments reported here, performance measures of speed, accuracy and continuous manual control were found to satisfy criteria such as sensitivity to practice and to individual differences. Several workload measures, particularly the DRA Workload Scales, also provided useful and reliable information. However, provision of performance feedback to the subject during training sessions had a limited effect on skill acquisition. On completion of this series of experiments, standardised batteries of measures will be specified for application to training.

1 INTRODUCTION

This paper reports the results of experimental research carried out under the EUCLID programme on 'Military Application of Simulation and Training concepts based on Empirical Research' (MASTER). MASTER is a comprehensive European project on tri-service simulator-based training for mobile weapon systems. The experiments reported here were part of an effort to develop validated general-purpose batteries of measures for application to training programmes. Most military training requires 'overlearning', such that task performance becomes increasingly automatic and makes as little demand as possible upon the limited mental resources of the operator. Thus, in these experiments emphasis was placed upon not only the use of objective performance measures but also the possible utility of workload measurement to demonstrate learning gains after performance on the training task has reached asymptote.

At the beginning of the EUCLID project, the military functions relevant to mobile weapons systems were identified as navigation, mobility, co-ordination, target acquisition, weapon delivery, self-defence, and system management. A literature review was conducted to identify performance measures relevant to these functions and to an associated 'skill taxonomy'. The experiments reported here addressed the psychometric properties of these measures. Measures found to be acceptable will be included in a battery from which trainers can select those most appropriate to their task.

Many studies have shown that workload measures, such as the power at 0.1 Hz of heart rate variability (HRV), are sensitive to task complexity and effort; however, such measures have seldom been used in the context of training. Unlike performance measures, workload measures are not dependent upon the precise nature of the training task used. It should therefore be possible to specify a standardised battery of workload measures that can be applied in any training programme to identify changes in workload during skill acquisition.

A secondary aim of the present series of experiments was to determine whether provision of feedback to the subject concerning performance during training would influence the learning process. If learning was found to be enhanced, a clear implication would be that feedback should be incorporated routinely into training programmes.

Experiments were conducted to encompass all the military functions described above. However, in the present paper only those addressing self-defence and system management are reported.

1.1 Measures

Performance and workload measures were selected (Farmer et al[1,2,3]) on the basis of several criteria, including those of Vreuls and Obermayer[4]:

- *Evidence of effectiveness in previous literature*
  The measures selected had all been used in a variety of contexts, although their utility in training research had not necessarily been demonstrated

- *Ease of use by non-specialised personnel*
  Some powerful measures, such as the electroencephalogram (EEG), were considered too difficult to implement in training programmes

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- *Practical considerations*
  Factors such as the cost of and ease of access to specialised equipment, suitability for automatic recording, and degree of disruption of trainees' performance were considered

- *Range of application*
  Measures that could be applied only to a narrow range of tasks were avoided where possible, to constrain the size of the resulting battery

- *Suitability for use as basis of feedback to trainee*
  Some measures required lengthy off-line data processing and were therefore unsuitable for the provision of feedback; others could easily be analysed and presented during training sessions

- *High correlation with operational performance*
  Most of the measures had been used successfully in applied studies

- *Face validity*
  Face validity for both training staff and trainees was considered a pre-requisite of the measures

1.2 Performance measures

Only the performance measures used in the experiments reported here are described. A much wider range of measures was addressed in the complete series of experiments.

1.2.1 *Accuracy*

Accuracy was considered an essential aspect of performance during training, and featured in most of the experiments in this series.

1.2.2 *Reaction time*

The time to respond to discrete stimuli was also considered fundamental to many training tasks. In these experiments, reaction time (RT) was recorded to the nearest ms, to ensure that even minor changes in performance might be detected.

1.2.3 *Continuous manual control*

Continuous manual control is a feature of many military tasks (e.g., tank driving, control of aircraft attitude, weapon aiming). Its laboratory counterpart is the 'tracking' task, in which the subject typically attempts to maintain the position of a moving cursor on a target using a control device such as a joystick or mouse.

1.3 Workload measures

Three types of workload measure were used: performance-based, subjective, and physiological.

1.3.1 *Performance-based measures*

Workload can be assessed by performance on either the primary or secondary task. In this study, a secondary-task performance measure was included to test the notion that benefits might be observable even after performance on the primary task had reached asymptote, since overlearning on the primary (training) task would produce greater spare capacity to process secondary-task stimuli. The secondary-task method selected was probe RT, in which subjects were required to respond to auditory stimuli presented at unpredictable intervals during the training task.

1.3.2 *Subjective measures*

The following subjective workload rating scales were selected for use in the experiments:

- Rating Scale Mental Effort (RSME)
- Bedford scale
- DRA Workload Scales (DRAWS)

RSME and the Bedford scale are uni-dimensional measures, whereas DRAWS is multi-dimensional. The former may be useful for purposes such as provision of simple feedback to the trainee; the latter can provide the trainer with more detailed information concerning sources of high workload.

RSME is a uni-dimensional rating scale requiring subjects to indicate how much effort they had to invest to perform the task (Zijlstra and van Doorn[5]; Zijlstra[6]). Subjects mark their responses on a vertical line, which has a scale of 0-150 and verbal anchors ranging from 'not at all effortful' to 'very effortful'.

The Bedford scale is a unidimensional rating scale of subjective workload, originally developed for the assessment of pilot workload (Roscoe[7]). It addresses 'spare mental capacity', and represents a hierarchical decision tree that produces a rating of 1-10.

DRAWS is a validated multi-dimensional workload assessment technique, comprising four scales: input demand; central demand; output demand; and time pressure (Farmer et al[8]). These scales correspond to the four workload factors derived statistically from a large set of performance and workload data.

1.3.3 *Physiological measures*

Many physiological measures have been studied as possible indices of workload, with varying degrees of success. The literature review led to the conclusion that heart rate variability (HRV), or more specifically the power of the 0.1Hz component of the HRV frequency spectrum, was most appropriate for the present purposes. Mulder[9] and Mulder and Mulder[10] showed that HRV in the frequency band 0.07-0.14 Hz diminished during tasks

requiring high mental effort. HRV was recorded in the present experiments, but will not be reported here.

1.4 Hypotheses

The hypotheses tested in these experiments are described below.

1.4.1 *Sensitivity*

It was hypothesised a) that the chosen performance and workload measures selected would be sensitive to ability differences between individuals, and b) that the performance measures would be sensitive to the effects of learning until asymptote was reached, whereas the workload measures would continue to show benefits even after performance asymptote.

1.4.2 *Reliability*

Reliability refers to the consistency of a measure recorded under comparable conditions. It was hypothesised that the measures would demonstrate a high level of reliability, expressed in terms of the residual variance after the effects of practice and of subjects had been accounted for.

1.4.3 *Validity*

It was hypothesised that the measures would achieve an acceptable level of validity. The following aspects of validity were examined:

- *Construct validity*
  Construct validity (the extent to which the measures provided scores that were consistent with theoretical predictions) was assessed by means of variation in the difficulty of some of the tasks, with the prediction that more difficult versions would be accompanied by poorer performance scores and higher workload ratings.

- *Concurrent validity*
  Concurrent validity (agreement between the measure and other available measures) was investigated by correlating different workload measures for the same task.

1.4.4 *Effects of feedback*

It was hypothesised that performance and workload measures would be sensitive to provision of feedback to the subject concerning performance.

1.5 Statistical methods

For each measure, the data were subjected to analysis of variance (ANOVA) with factors of session (1/2), block of five runs in each session (1/2), run (1-5), and subjects. Task difficulty and feedback were included as factors as appropriate. Constraints of space preclude reporting of F-ratios for effects; however, all effects reported are significant at the 0.05 level or better.

2 EXPERIMENT 1: SELF-DEFENCE TASK

2.1 Introduction

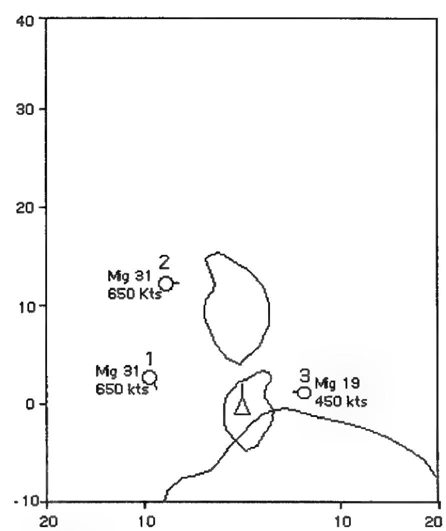
In the self-defence task, task difficulty was varied. This manipulation permitted assessment of the 'construct validity' of the workload measures: on theoretical grounds, workload scores should increase as a function of difficulty.

2.2 Method

2.2.1 *Subjects*

Twelve subjects (eight males and four females) participated in the experiment; six were assigned to the difficult condition and six to the easier condition. The subjects, whose average age was 24 years, were students recruited from a local college and were paid for participation in the experiment; they also participated in Experiment 2.

2.2.2 *Apparatus*



The experiment was run using a portable Apple Macintosh computer for the threat assessment task, and a PC for probe RT and RSME. The cardiac signal was recorded by an Apple Macintosh MacLab system and monitor. Headphones were used for the presentation of the probe RT stimuli and footswitches were used for the subject's responses.

2.2.3 *Materials*

In addition to the computerised RSME ratings, subjects completed paper-and-pencil versions of the Bedford scale and DRAWS.

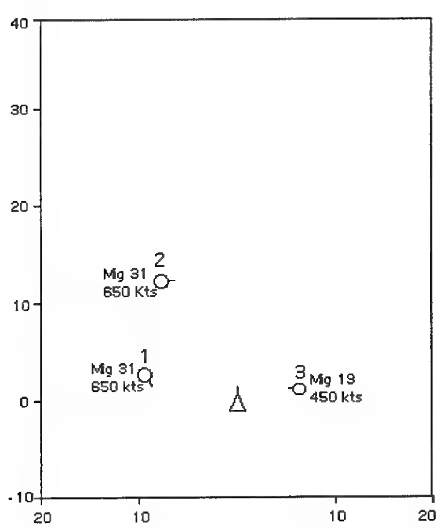
2.2.4 *Task*

A validated threat assessment task created at DRA was used. It was originally developed as an explanatory tool to support pilot decision making within the context of air combat threat assessment. The subject's task involved the identification of hostile aircraft presented on a pseudo-radar display. The hostile aircraft were Mig 19s (defined as carrying short-range missiles) or Mig 31s (defined as carrying medium-range missiles).

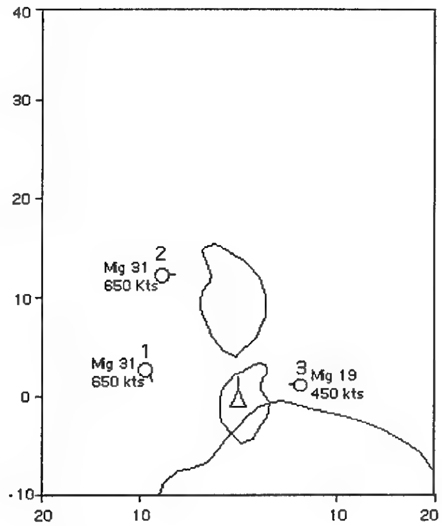
The hostile aircraft were represented as travelling at either 450 or 650 knots and with a relative closure angle to own aircraft of 90, 120, 150 or 180 degrees, indicated by a line emanating from the hostile aircraft symbol. There were therefore 16 stimulus combinations (two aircraft types x two speeds x four angles), representing different degrees of threat; all were presented during each run On each trial, three hostile aircraft were displayed in addition to the subject's 'own' aircraft. The subject's task was to decide which of the three hostile aircraft presented the most immediate threat, and to respond by pressing a button corresponding to aircraft number. Task difficulty was manipulated by the use of a second form of display that provided the subject with a graphical representation of the hostile aircraft's missile envelope (a volume of space around the target within which a missile fired from the launch aircraft would hit the target), determined by the speed and missile type of the hostile aircraft. This pictorial representation had been shown in previous DRA studies to improve threat assessment by reducing the amount of processing required to perform the task. Thus two levels of difficulty were used: an easy pictorial condition and a more difficult textual condition (see Figure 1).

Figure 1. Examples of threat assessment stimuli

a) pseudo-radar display: difficult textual condition



b) pseudo-radar display: easy pictorial condition



2.2.5 *Design*

A mixed design was used, with a between-subjects factor of task difficulty and within-subjects factors of sessions, blocks and runs. The dependent variables were RT and error rate.

2.2.6 *Procedure*

Subjects were assigned randomly to the 'easy' and 'difficult' conditions. After receiving general instructions, baseline electrocardiogram (ECG) was recorded for 5 min whilst the subject sat quietly. The subject wore headphones throughout each 3-min run for the administration of the probe RT stimuli. A 30-sec familiarisation period was given before the first run began. At intervals during each run, the subject was presented with one of two possible probe RT task tones and responded by pressing the relevant footswitch. After each run, the subject was asked to complete the workload scales. Each session of 10 runs lasted approximately 90 min.

2.3 Results

All measures showed a reliable effect of subjects, indicating sensitivity to individual differences. Other effects are described in more detail below.

2.3.1 *Performance data*

The performance data are summarised in Table 1. RT declined within each of the two sessions. For errors, there was a reliable interaction between session and run: the decline in error rate during session 1 was absent during session 2.

Table 1. RT and error data for the self-defence task in Experiment 1

Session 1	Block 1		Block 2	
	Diff	Easy	Diff	Easy
RT (ms)	2949	2800	2710	2697
Errors (%)	39.3	37.0	31.9	32.3
Session 2	Block 1		Block 2	
	Diff	Easy	Diff	Easy
RT (ms)	2571	2771	2593	2621
Errors (%)	39.3	41.5	40.4	44.1

2.3.2 *Workload data*

The subjective workload data are summarised in Table 2, and the results of statistical analysis in Table 3. DRAWS and probe RT task scores reflected the improvement in threat assessment task performance, but Bedford and RSME ratings did not. Task difficulty affected the rate at which DRAWS ratings decreased with practice. The easy version of the task produced lower perceived central demand but higher perceived time pressure, presumably because of more rapid responding to the stimuli.

2.3.3 *Covariance between measures*

Covariance between the measures was investigated in three ways:

- between-subjects: the extent to which the subjects' mean scores were consistent from measure to measure
- between-runs: the extent to which measures covaried consistently with practice (over the set of 20 runs)
- residual: covariance after allowing for subjects and runs; a significant association implies an intimate correlation in the behaviour of the two measures.

2.3.3.1 *Between-subjects*

The subjective workload measures were all positively associated, the DRAWS scales showing the strongest intercorrelations. There was relatively little association, however, between probe RT task measures and the subjective measures. DRAWS measures were positively associated with threat assessment task measures. Errors and RT were negatively related in the probe RT task, suggesting that subjects were adopting different speed/accuracy criteria. Errors in the probe RT task were also negatively related to errors in the threat assessment task, suggesting differences between subjects in the relative priority given to the two tasks.

Table 2. Mean workload scores in Experiment 1

Session 1	Block 1		Block 2	
	Diff	Easy	Diff	Easy
DRAWS Input	62.9	55.0	54.0	49.7
DRAWS Central	63.4	51.5	54.6	47.8
DRAWS Output	43.6	33.8	39.5	30.2
DRAWS Time Pressure	45.4	51.6	41.6	49.5
RSME	45.8	37.2	39.8	37.7
Bedford scale	5.1	4.7	4.4	4.5
Probe RT (RT in ms)	876	891	807	879
Probe RT (% error)	13.0	10.8	8.2	11.3
Session 2	Block 1		Block 2	
	Diff	Easy	Diff	Easy
DRAWS Input	52.8	37.1	48.4	32.8
DRAWS Central	52.0	40.5	49.9	34.2
DRAWS Output	40.3	27.2	40.0	23.6
DRAWS Time Pressure	38.5	44.5	42.3	41.6
RSME	35.6	36.4	34.7	32.6
Bedford scale	4.2	4.2	4.2	3.6
Probe RT (RT in ms)	749	827	793	861
Probe RT (% error)	7.4	7.1	5.8	7.5

Table 3. Summary of significant effects for workload measures

Measure	Effect	Description
DRAWS Input, Central	Run	General decline with practice
DRAWS Central	Block x Session x Difficulty	Improvement in session 1 for difficult task greater than that for easy task
DRAWS Time Pressure	Block x Session x Difficulty	Improvement in session 1 for difficult task greater than that for easy task
Probe RT task - RT	Session	RT lower in second session
	Session x Block	Block 1 of sessions 1 and 2 different; no difference for block 2
Probe RT task - errors	Session	Error lower in session 2

2.3.3.2 *Between-runs*

The subjective workload measures were all highly correlated, indicating a similar pattern of change with practice. RT in the threat assessment task and errors in the probe RT task were positively related to the subjective workload measures, indicating that performance changes over time were reflected in corresponding workload changes. However, threat assessment errors were negatively related to the subjective workload measures, perhaps because of a speed/accuracy trade-off within that task (higher workload being associated with longer RT but lower error rate).

2.3.3.3 *Residual*

There was a general positive association between the subjective workload measures. There was little relationship between threat assessment and probe RT task performance, but a negative association between threat assessment errors and perceived input and central demand.

2.4 Discussion

Both RT and error rate on the threat assessment task were found to be sensitive to individual differences and to the effects of practice. These measures therefore appear to satisfy the primary criteria for acceptance as performance indices in training programmes.

Although the subjective workload measures were inter-correlated, DRAWS appeared to be most sensitive to the effects of training: unlike the Bedford scale and RSME, DRAWS was sensitive both to practice and to task difficulty. Probe RT appeared to offer some utility as a workload measure. However, it is unclear whether the performance improvement on this task reflected increasing spare capacity as performance improved on the threat assessment task, or simply the effects of training on the probe RT task itself. Moreover, there were indications that subjects were allocating different levels of priority to the primary and secondary tasks, a factor likely to complicate the interpretation of training data.

In summary, DRAWS appears to be the suitable workload measure of those studied in this experiment.

3 EXPERIMENT 2: SYSTEM MANAGEMENT TASK

3.1 Introduction

The Multi-Attribute Task (MAT) Battery, developed by NASA, was used as the systems management task. In this task, presence or absence of feedback to the subject was used as an independent variable to determine its effects of learning.

3.2 Method

3.2.1 *Subjects*

See Experiment 1.

3.2.2 *Apparatus*

A PC controlled the systems management task. The apparatus for the other measures was identical to that used in Experiment 1.

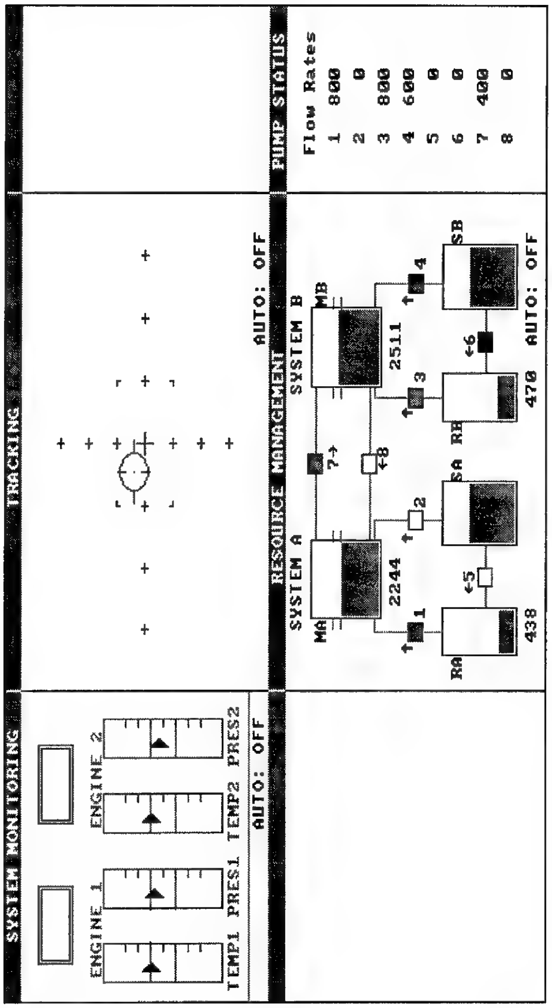
3.2.3 *Materials*

See Experiment 1.

3.2.4 *Tasks*

The MAT Battery is a set of tasks analogous to activities performed in-flight by aircrew, but can be used on non-aircrew subjects (Figure 2). It comprises three task elements performed concurrently: tracking, monitoring, and resource management. A further communication task is available, but was not used in this experiment.

Figure 2. The MAT Battery display



In the compensatory tracking task, the subject was required to keep the target located in the centre of a screen window using a joystick. In the monitoring task, the subject monitored four vertical scales and two lights for changes in system state. In their normal condition, the pointers of the vertical scales fluctuated around the centre of the scale; at intervals, a pointer on any of the scales deviated from the centre position to one deviation above or below the centre. The subject responded by pressing a button corresponding to the scale. Two warning lights, one red and one green, also required to be monitored, the subject being instructed to respond to the absence of the green light and the presence of the red light. In the resource monitoring task, the subject managed a fuel supply, with the goal of maintaining tanks A and B at 2500 units each by turning on or off any combination of eight pumps. Pump failures could occur and were denoted by a red area on the failed pump, but the subject was unable to respond to such failures. Numbers below tanks A, B, C, and D represented the amount of fuel in each tank. Tanks A and B were depleted of fuel at a rate of 800 units/min. Subjects were therefore required to transfer fuel from the other supply tanks. The flow rates for each pump were shown in a status window next to the resource management window.

3.2.5 *Design*

The design was similar to that for Experiment 1, except that the factor of task difficulty was replaced by that of feedback. The dependent variables were RMS tracking error, errors on the monitoring tasks, mean reset time, and number of pump activations.

3.2.6 *Procedure*

The procedure was similar to that used in Experiment 1.

3.3 Results

As in Experiment 1, each measure showed reliable differences between subjects.

3.3.1 *Performance data*

The data are summarised in Table 4; significant effects are described in Table 5.

Table 4. Mean performance scores in Experiment 2

Session 1	Block 1		Block 2	
(C=Control; F=Feedback)	C	F	C	F
Tracking (RMS error)	54.0	35.0	48.2	25.3
Scale monitoring (RT in seconds)	7.3	7.8	6.5	5.4
Scale monitoring (errors)	20.3	16.4	19.4	14.5
Light monitoring (RT in seconds)	2.7	3.0	1.8	2.1
Light monitoring (errors)	15.6	5.3	5.6	0.0
Resource management (deviation)	455.0	363.0	252.0	222.7
Session 2	Block 1		Block 2	
(C=Control; F=Feedback)	C	F	C	F
Tracking (RMS error)	39.3	23.0	38.2	21.8
Scale monitoring (RT)	5.9	6.1	5.5	4.4
Scale monitoring (errors)	16.4	11.7	15.3	11.6
Light monitoring (RT)	2.0	1.8	1.8	1.6
Light monitoring (errors)	2.2	0.0	1.1	0.0
Resource management (deviation)	167.7	240.6	155.6	180.2

Table 5. Summary of performance effects in Experiment 2

Task	Effect	Description
Tracking	Session	Lower error in session 2
	Block	Lower error in block 2
	Session x Block	Decreasing error only during session 1
Scale monitoring	Session	Lower RT/error in session 2
	Block	Lower RT in block 2
Light monitoring	Session	Lower RT in session 2
	Block	Lower RT/error in block 2
	Session x Feedback	Performance improved only for subjects receiving feedback
	Block x Session	Decrease in error and RT only in session 1
Resource manageme nt	Session	Deviations lower in session 2
	Block	Deviations lower in block 2
	Session x Block	Decreasing deviation only during session 1

The tasks showed clear effects of practice, with evidence that asymptote was reached in session 2. Feedback was shown to improve learning, but only in the lights monitoring task.

3.3.2 *Workload data*

The workload data are summarised in Tables 6a and 6b; significant effects are described in Table 7. All workload measures were sensitive to the effect of practice, but were unaffected by the provision of feedback.

Table 6a. Mean workload scores in Experiment 2 Session 1

Session 1	Block 1		Block 2	
(C= control; F = feedback)	C	F	C	F
DRAWS Input	58.0	70.0	44.1	65.2
DRAWS Central	41.7	54.0	35.5	51.8
DRAWS Output	52.4	67.5	40.1	61.2
DRAWS Time Press.	40.6	49.8	35.4	45.0
RSME	68.6	58.9	59.9	49.9
Bedford scale	5.8	5.6	5.1	4.8
Probe RT (RT in ms)	1044	799	949	743
Probe RT (% error)	17.7	28.8	12.0	15.7

Table 6b. Mean workload scores in Experiment 2 Session 2

Session 2	Block 1		Block 2	
(C= control; F = feedback)	C	F	C	F
DRAWS Input	41.7	59.6	33.8	54.3
DRAWS Central	31.6	46.8	27.3	41.0
DRAWS Output	40.5	53.2	32.0	49.3
DRAWS Time Press.	26.9	39.3	21.2	35.3
RSME	53.5	41.0	47.0	37.4
Bedford scale	5.0	4.0	4.4	3.5
Probe RT (RT in ms)	884	780	894	803
Probe RT (% error)	8.9	13.3	9.8	13.6

Table 7. Summary of workload effects in Experiment 2

Measure	Effect	Description
DRAWS Input, Central and Output; Bedford; RSME	Session	Lower in session 2
DRAWS Input, Output; RSME	Block	Lower in block 2
Probe RT task - RT	Session x Block	RT decreased in session 1 but not session 2
Probe RT task - errors	Session x Block	Error decreased in session 1 but not session 2

3.3.3 *Covariance of Measures*

3.3.3.1 *Between-subjects*

The DRAWS measures were generally positively inter-correlated, although output demand showed the lowest levels of association. Bedford and RSME scores were positively associated with each other, but not strongly associated with DRAWS scores. Probe RT was positively with RT on the scale monitoring task. Errors on the light monitoring task were positively correlated with deviations in the resource management task and with RMS error. Input demand was negatively correlated with RMS error. Finally, RT in the light monitoring task was negatively related to DRAWS input demand and RSME scores. These results suggest that subjects with higher levels of performance generally provided lower workload scores, but rated input demand as higher.

3.3.3.2 *Between-runs*

There were strong positive associations between the subjective workload measures. All the performance measures except errors on the scale monitoring task were significantly positively associated with each other and with the subjective workload measures. Thus, the changes in the measures with practice were in general consistent; scale monitoring error deviated from this pattern, and was found to increase rather than decrease over time.

3.3.3.3 *Residual*

The subjective workload scores were all positively inter-related. There were positive associations between average deviations on the resource management task and RMS error on the tracking task, and between RT on the scale monitoring task and error on the light monitoring task. Scale monitoring error and RMS error were negatively correlated. Otherwise, the performance measures were poorly correlated with each other.

Probe RT was negatively correlated with light monitoring RT, but probe RT, deviation, and RMS error were all positively correlated. Error in the probe RT task was positively correlated with scale monitoring error.

A positive correlation was observed between probe RT and both central demand and RSME ratings; moreover, error in the probe RT task correlated with RSME ratings.

Output demand ratings were negatively associated with deviation and RMS error, suggesting that high motor activity produced better performance on tasks with a strong motor component. In other respects, poor performance occurred when demand was high: central demand and light monitoring error were positively correlated, as were Bedford ratings and scale monitoring error.

3.4 Discussion

RT, error rates and RMS error were all found to be clearly sensitive to individual differences and to practice. The general pattern was for improvement in session 1, performance stabilising in session 2. The use of these measures in training programmes is therefore supported.

Performance on the system management tasks showed a relatively complex pattern of associations. It is likely that several factors contributed to this pattern. General ability might be expected to produce positive associations between task scores; however, concurrent performance of the tasks would produce a tendency for negative associations, since attention to one task would divert mental resources from the others.

The Bedford and RSME scales were more sensitive than in Experiment 1, but again showed fewer reliable effects than DRAWS. Moreover, DRAWS revealed that different aspects of workload were differentially related to performance. In general, high perceived demand reflected poor performance, but output demand tended to vary as a function of performance on motor tasks, presumably reflecting increased motor activity (and hence output demand) when subjects were performing well on these tasks.

Probe RT was associated with several performance and subjective workload measures. However, it was negatively correlated with light monitoring performance, suggesting a trade-off between these tasks.

There was some evidence for a beneficial effect of feedback on performance. However, this effect was apparent only for one performance measure, and there was no corresponding decrease in perceived workload.

4 GENERAL DISCUSSION AND CONCLUSIONS

4.1 Hypotheses

The findings are considered below in terms of the original hypotheses.

4.1.1 *Sensitivity*

The performance measures were sensitive to both individual differences and practice. The same was generally true of the workload measures, particularly DRAWS.

4.1.2 *Reliability*

The measures tended to vary consistently as a function of practice, and strong underlying associations were found between workload and performance measures.

4.1.3 *Validity*

Construct validity was demonstrated for DRAWS in the form of sensitivity to task difficulty. Most measures were sensitive to practice, another aspect of construct validity. Concurrent validity was demonstrated by good levels of association between workload measures.

4.1.4 *Effects of feedback*

Although some benefit of feedback was noted, this factor did not exert a major influence on skill acquisition.

4.2 Conclusions

These findings suggest that it will be possible to develop useful standardised batteries of performance and workload measures. The final form of the batteries must await completion of this series of experiments, but is likely to include DRAWS and performance measures of RT, accuracy and RMS error. On the present evidence, the provision of feedback appears to have little effect on skill acquisition.

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TRAINING OF FUTURE FIGHTER PILOTS

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SUMMARY

Before starting the pilot school in USA the young, G-inexperienced student pilots were trained on the human centrifuge (HC) at Koenigsbrueck near Dresden, Saxony. This G-training is an integrated part of their one-week basic physiological training course. The objective of this course is, that the students become familiar with the G-environment safely.
In the beginning of the G-training the student pilots were exposed to the same G-profiles as the pilot candidates. On the second day they were trained in muscle straining and anti-G-breathing technique during moderate HC runs with and without anti-G-equipment. Then they were able to use these techniques in the HC during active profiles. The result and effectiveness of this training will be documented by a special qualification profile. This qualification profile consists of the same passive linear profile as on the first day. The student pilots don't wear anti-G-trousers. During the increasing G-load they should first stay relaxed, until they reach their 50% peripheral light loss (1. PLL). In this moment they activate their muscle straining, until they reach the second time PLL (2.PLL). Now they start the anti-G-breathing technique until they reach their individual maximum active G-tolerance (3. PLL).
The results of the G-training of the first 198 student pilots, mean age 22.9 ± 1.7 years, mean height 180.3 ± 5.5 cm, body mass 76.8 ± 7.9 kg indicate, that that the muscular straining manoeuvre will increase the G-tolerance by about 1.0 g_Z, and the additional breathing manoeuvre will increase the G-tolerance by another 1.5 g_Z, totally 2.5 g_Z even under artificial, not operational conditions.

The short introduction in performing anti-G-straining and -breathing technique seems to be very effective. It might avoid negative experience of G-LOC during the pilot school and add some self-confidence to the student pilot.

INTRODUCTION

In connection with the evaluation of pilot candidates the new concept of the Office of the Surgeon General of the German Air Force established an anti-G-training program for student pilots. The contents of this training in the human centrifuge (HC) were modified at Koenigsbrueck.

The demand of this training became more urgent for the GAF in preparation for the new European Fighter Aircraft respectively the European Fighter 2000. The new concept was developed with respect of the necessity of a human centrifuge aided acceleration training of the future fighter pilot generation. This concept includes diagnostic centrifuge runs for selection, training for G-inexperienced student pilots, and special training and qualification runs for pilots of modern high performance fighter aircraft.

GENERAL

Control System and Acceleration Profiles

The HC at Koenigsbrueck can be operated in three different modes. In the first mode, the manual control mode (MM), the operator manually inputs with potentiometers the parameters for the centrifuge run. In this mode, the operator initiates the

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start and stop of the centrifuge. The MM is used for maintenance and inspection of the HC.

In the second mode, called the automatic mode (AM), pre-programmed acceleration profiles are used for automatic HC-runs. This accomplishes two advantages:

- the pilot is provided with precisely the same stimulation at exactly the same G-level, when the same profile is selected and
- provides accurate, repeatable runs between different pilots for identical profiles.

The AM is used in the „warm-up" profile, in linear profiles and some interval profiles. These profiles are the „passive" runs.

Finally, the pilot control mode (PM) allows the operator to use a pre-programmed parameter field, which sets the maximum conditions, and provides a varying target on the monitor in the gondola. The pilot initiates and has control of the onset, offset and G-level, according to his control stick motions within the limits set by the selected parameter field.

In the PM the complete parameter field is stored on the control computer. Such a parameter field consists of

- the selected control element
- maximum G-level
- maximum onset and offset-rate
- the basic acceleration level and
- maximum duration of time of the run.

The PM is used in most of the training profiles, including the STANAG-profile. These profiles are the „active" runs.

METHOD

The common objective especially of training with the HC is to ensure, that both the student pilot or pilot and the examiner get information about the individual actual acceleration tolerance and the conclusion, which is the effect with regard to personal health, pilot career, and flying safety. In this context not fixed hurdles like the STANAG-profile are the most important profiles, but individual training profiles to reach this goal.

The advantage of the training during active runs, controlled by the student pilot himself in the pilot control mode, is the interaction between the instructor on the console and the student pilot in the gondola, to use time and safe acceleration limits to train anti-G techniques.

Training of student pilots

Before starting the pilot school in the USA the young, G-inexperienced student pilots and students for the weapon system officers' school join the basic physiological training course at Koenigsbrueck. Their flight experience is about 18 to 20 flying hours on the Beech Bonanza F 33 lightweight aircraft during their screening period in Arizona. The first course exclusive for G-training started at Koenigsbrueck November 1993, and the last course exclusive for the G-training ended in February 1995. Since March 1995 the G-training is an integrated part of the one-week physiological basic training course at Koenigsbrueck.

The objective of this course is, that the students become familiar with the G-environment. They should learn to perform active maneuvers to increase their G-tolerance, thus the effectiveness of muscle straining maneuvers and especially of the correct breathing technique, they should learn, how effective the anti-G equipment works, they should get the impression, how to avoid G-LOC, and they might get the impression and experience of G-LOC.

The training program consists of:

- Briefing about acceleration physiology, the effects of acceleration forces to the human organism, especially the cardiovascular system, and the instructions for the first passive evaluation in the HC,
- starting with the „warm-up" interval-profile EP 01 (Fig. 1). No anti-G equipment will be worn,

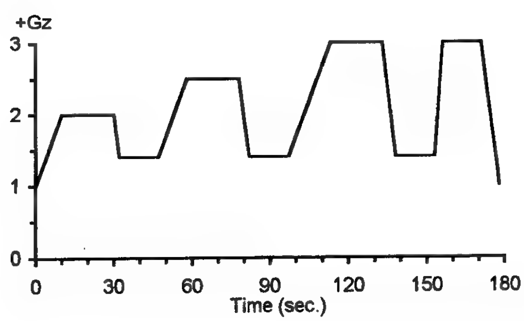

Fig. 1:

warm-up-run profile EP 01:
first 3 onset: 0.1 gs^{-1}, last onset 0.5 gs^{-1}
offset: 0.3 gs^{-1}, first 3 plateaus 20 s, last 15 s.

- followed by the linear profile LP 01 (Fig. 2) with a gradual onset of $0.1\ gs^{-1}$, no anti-G equipment, to determine the individual natural G-tolerance.

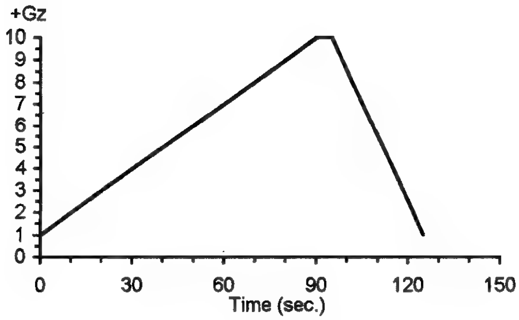

Fig. 2:

linear profile LP 01: gradual onset: $0.1\ gs^{-1}$
gradual offset: $0.3\ gs^{-1}$

- Theory and exercise of muscular anti-G straining technique and anti-G breathing technique, supported by a breathing monitor device, is the step, before the student will practice these techniques the next day in the HC - equipped and supported by anti-G-trousers.

- The individual relaxed G-tolerance will be the clue for the following active and passive training profiles. To increase the effectiveness of a short training course and to avoid unnecessary G-LOC without any training effect, the following profiles will be limited to a maximum G-level of $4.0\ g_z$ to $6.0\ g_z$. The reason is, that the students should stay on the borderline between their individual G-tolerance and the optimal G-level for the special task, they have to fulfill during the following profiles.

- This first training profile is an active profile with an individual G-limitation. The profile in the PM gives the advantage, to understand the effectiveness of a good or a poor technique during an active initiated sustained G-profile with free eligible duration. The G-level should be high enough, that without an accurate breathing maneuver G-LOC may occur due to the possible long duration of the profile, but which is low enough, that the student may learn, how easily and effective the grayout can be terminated by adequate active anti-G maneuvers.

- The next profile is an active interval training profile in the pilot control mode (PM), consisting of four plateaus with an increasing G-level of $3.0\ g_z$, $3.5\ g_z$, $4.0\ g_z$, and $4.5\ g_z$ (Fig. 3). The visualization of this active profile is shown in Fig. 4. After this pretence the student should perform G-profiles of his own with different G-onsets and G-levels. The maximum G-level is $4.5\ g_z$ in the minimum version and $7.0\ g_z$ in the maximum version of this active profile. The anti-G-trousers will be worn.

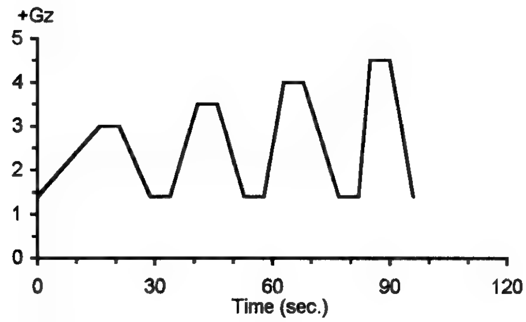

Fig. 3:

active training profile: pretence - profile

1st plateau $3.0\ g_z$, onset: $0.1\ gs^{-1}$, offset $0.3\ gs^{-1}$,
2nd plateau $3.5\ g_z$, onset: $0.3\ gs^{-1}$, offset $0.3\ gs^{-1}$,
3rd plateau $4.0\ g_z$, onset: $0.5\ gs^{-1}$, offset $0.3\ gs^{-1}$,
4th plateau $4.5\ g_z$, onset: $1.0\ gs^{-1}$, offset $0.3\ gs^{-1}$.
Plateau duration 15 seconds.
After this pretence: active free maneuvering up to $4.5\ g_z$ or up to $7.0\ g_z$

The visualisation of this active pretence is realized in the pilot control mode (PM) of the HC at Koenigsbrueck, using the following display in the gondola:

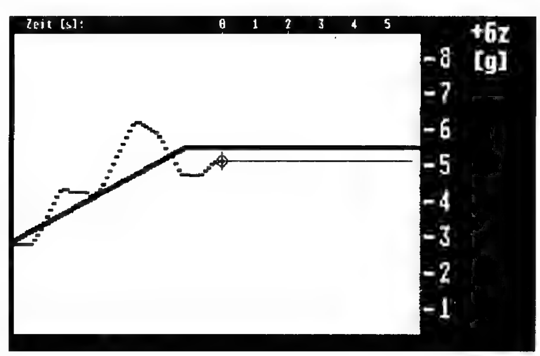

Fig. 4: coming up G-level indication

The display (Fig. 4) shows a curve which moves from the right to the left hand side and displays the G-level of the target. The G-level commanded by the pilot is also displayed in a dotted line.
This display mode in the pilot control mode (PM) is very simple, but effective for basic training programs.

- The last and qualification profile - without anti-G trousers - is the passive linear profile LP 01, consisting of three parts. To document the effectiveness and the effort of the training the student should perform the anti-G-maneuvers in the following procedure:

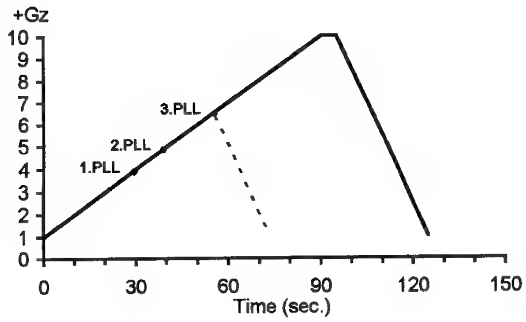

Fig. 5:

qualification profile
linear profile LP 01: gradual onset: 0.1 gs^{-1}
gradual offset: 0.3 gs^{-1}

1. PLL: relaxed G-tolerance, no anti-G-maneuvers
2. PLL: G-tolerance increased by muscular straining maneuvers
3. PLL: G-tolerance increased by additional anti-G-breathing maneuvers

- First: The student should stay relaxed until he get the first impressions of beginning grayout symptoms. This point will be announced by the word „now" by the student. On „now" he starts the muscular straining maneuver. This actual G-level will be documented and denominated as the first peripheral light loss (1.PLL).

- Second: When the student get the second time his beginning grayout symptoms during his muscular straining phase he takes a deep breath and begins with the anti-G-breathing maneuver. This actual G-level also will be documented and denominated as the second peripheral light loss (2.PLL).

- Third: When the student get the third time his grayout or even blackout symptoms, he should terminate his run voluntary by releasing the „dead man" buttom: Termination by the student. Most the times the profile will be terminated by the instructor however due to typical objective indications, thus as depressed ear pulse curve, inadequate or missing answers to the diode-light signals, exceeding the limit of the maximum heart rate, or passing the G-level of 7.0 g_z. This maximum G-level is chosen as safety limit to avoid unnecessary risks or secondary effects like severe petechias, because the lower body of the student isn't protected by anti-G-trousers.
7.0 g_z should be enough for the first attempt.

RESULTS

Since November 1993 total 198 student pilots were trained in this or a comparable manner. The results of these 198 student pilots:

Mean age: 22.9 ± 1.7 y (20 ... 27 y)
mean height: 180.3 ± 5.5 cm (168 ... 191 cm)
mean body mass: 76.8 ± 7.9 kg (58 ... 98 kg)

The natural, relaxed G-tolerance:

4.8 ± 0.6 g_z (3.5 ... 6.2 g_z).

The qualification results of these 198 students in the three step linear profile:

1. PLL: 3.8 g_z ± 0.5 g_z (2.4 .... 5.6 g_z)
2. PLL: 4.7 g_z ± 0.6 g_z (3.4 .... 6.5 g_z)
3. PLL: 6.3 g_z ± 0.6 g_z (4.9 .... 7.4 g_z)

This indicates, that the muscular straining maneuver will increase the G-tolerance by about 1.0 g_z, and the additional breathing maneuver will increase the G-tolerance by another 1.5 g_z. On an average of 2.5 g_z the G-tolerance will be increased by both techniques even under worse conditions: the student has his first training of the technique, there are only 2 days of training, and the operational in-flight anti-G-technique is not used, thus as starting straining and breathing maneuvers simultaneous at the first beginning of the acceleration exposure to avoid blood pooling in the lower body compartment in the early phase of the acceleration exposure.

Training of pilots

The training or qualification program of pilots of high performance fighter aircraft will be terminated by the STANAG-profile instead of this linear three part profile. The STANAG-profile however is one integrated part of an active training profile with a G-limitation of 7 g_z, because now we prefer to fulfill the demands of the STANAG-profile in the active, the pilot control mode (PM). During the pretence profile the pilot can prepare himself for the minimum sustained 15 second of the +7 g_z plateau like in the operational real air combat scenario. He is in control of the controls. After an individual warm-up period he had to pull the stick in the full aft position from the 1.4 g_z idling plateau. With this stick movement he get a G-onset of about +2 gs^{-1}. This seems to be more effective than passive HC-runs like in earlier times.

STANAG-profile :

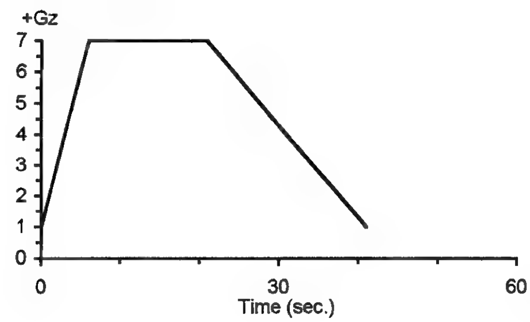

Fig. 6:

qualification profile ST 01 (STANAG 3827):
g-onset: > 1.0 gs^{-1}
plateau duration: > 15 s
gradual offset: 0.3 gs^{-1}

DISCUSSION

The human centrifuge at Koenigsbrueck, primarily constructed for medical research and diagnostic is now in service preponderant for pilot candidate selection and student pilot training. The effort of the student pilot training seems to be one great promising method to prepare the student pilots for the coming-up G-environment. The aim of this training is, to avoid unnecessary G-LOC not only during the pilot school, and to produce flying safety, and perhaps to reduce unnecessary mismatch feelings during the first realistic air combat training missions in the T 37 or T 38. Secondly student pilots with uncommon motion sickness problems in the HC, poor G-tolerance or even pathologic G-tolerance may be detected early enough, so that first further medical diagnostics could be done, before the expensive pilot school starts.

The training of our MiG-29 pilots and other pilots, which are designed to fly high performance aircraft, seems to be necessary. Although most of the pilots don't have difficulties to reach the qualification of the STANAG-profile, the poor and ineffective anti-G-technique, which needs a lot of wasted energy, shows us, that there was a lack of information on anti-G-techniques to most of the pilots in the past. To get the impression of the effectiveness of optimized anti-G-maneuvers might be one reason to join at least once the G-training course. To get the impression of their own limits and to produce self-confidence by getting on the limits in a safe environment might be an effective contribution to flying safety.

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AGARD - LS - 202
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AVIATION PHYSIOLOGY TRAINING IN THE 21st CENTURY

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1. SUMMARY

The Canadian Aeromedical Training Programme has recently undergone significant changes. Other countries are also reviewing their aeromedical training programmes and looking for new or different ways to provide the necessary academic training at the correct frequency using the best methods possible. The U.S. Navy has completed an extensive review of its programme and is currently exploring the possibility of providing continuation aeromedical training in conjunction with flight simulator training. The Royal Australian Air Force already uses an innovative approach to provide night vision training that may be appropriate for use by other countries. It seems inevitable that aeromedical training programmes will continue to change in the future. To ensure that these changes are appropriate and that they improve flight safety, it is essential that measurement tools be developed to assess current programmes and to determine what changes should be made. Due to current and potential changes in aeromedical training programmes, it would seem appropriate, in the interests of international standardization of aeromedical training in the future, to revise the terms of STANAG 3114.

2. INTRODUCTION

Like many other nations, Canada has had an aviation physiology training programme based on the NATO Standardization Agreement STANAG 3114, Aeromedical Training of Flight Personnel (1). However, with current budgetary and personnel cutbacks it has become necessary to evaluate the need, content and delivery method for aeromedical training. In Canada this process began in 1990 and is still ongoing with changes in curriculum, frequency and types of training all taking place. Even with these changes there are still areas which need to be explored in order to ensure that aircrew are receiving relevant training in an appropriate manner and at the correct interval.

3. CURRENT REQUIREMENTS

STANAG 3114, Aeromedical Training of Flight Personnel, details the minimum aeromedical training required for flight personnel to promote safety and efficiency in the operation of military aircraft. The STANAG specifies that aircrew receive initial and continuation training, and differentiates between fixed and rotary wing aircrew. It also supports the idea that training be "aircraft type or group specific with the instruction related directly to the aeromedical features and life support equipment of the aircraft type or group which the students are operating" (1). In addition, the maximum interval between training is five years.

3.1 Fixed Wing Initial Training

For fixed wing aircrew, initial training must consist of at least 30 hours of academic instruction and practical exercises including a hypobaric exposure to a simulated altitude of not less than 25,000 feet. In addition, if their aircraft are capable of flight above 35,000 feet, students must undergo a hypobaric exposure to a simulated altitude of between 43,000 and 45,000 feet for at least 30 seconds. This chamber flight must also include a personal hypoxia experience while

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breathing air at 25,000 feet. Other desirable practical exercises for these individuals include experience of rapid decompression, spatial disorientation and ejection forces. Academic instruction for fixed wing initial training includes a wide range of topics including but not limited to vision, hearing, hypoxia, hyperventilation, respiration and circulation, orientation and disorientation, oxygen equipment, flight clothing and survival.

3.2 Fixed Wing Continuation Training
Continuation training for fixed wing aircrew must include at least 6 hours of academic and practical training including a hypobaric exposure to a simulated altitude of 25,000 feet and a rapid decompression appropriate for the aircraft being operated by the student. Academic instruction for fixed wing continuation courses should be designed as a refresher of the subjects taught during initial aeromedical training

3.3 Rotary Wing Initial Training
For rotary wing aircrew, initial training must consist of at least 24 hours of academic instruction and practical exercises including a hypobaric exposure to a simulated altitude of between 18,000 and 25,000 feet with a personal hypoxia experience at 25,000 feet. Other desirable practical exercises for these individuals include experiencing spatial disorientation and underwater escape from aircraft. Academic instruction for rotary wing initial training includes a majority of the topics provided to fixed wing aircrew with notable exceptions being oxygen equipment, cabin pressurization and sustained positive and negative acceleration.

3.4 Rotary Wing Continuation Training
Continuation training for rotary wing aircrew must include at least four hours of academic training with no requirement to provide any practical training. As with fixed wing continuation training the academic instruction for rotary wing continuation courses should be designed as a refresher of the subjects taught during initial aeromedical training.

4. CANADIAN PROGRAMME PRE-1993
Historically Canada's Aeromedical Training Programme conformed to STANAG 3114 with minor reservations. For initial training, aircrew were separated into three classifications, Pilot, Navigator and Other Aircrew. Each of these classifications attended courses individually tailored to their job requirements and course lengths varied accordingly. As well, Canada previously divided continuation training into four categories by aircraft type, namely ejection seat, fixed wing pressurized, fixed wing unpressurized and rotary wing. This continuation training was required for all aircrew every three years regardless of aircraft type.

4.1 Initial Training
Under the previous Canadian programme, altitude chamber training requirements varied by the student's aircraft type. For aircrew operating ejection seat aircraft, initial chamber training included exposure to a simulated altitude of 43,000 feet with a personal hypoxia experience at 30,000 feet (Type II). In addition students experienced a simulated rapid decompression from ground level to 10,000 feet (Type III). For aircrew operating all other types of aircraft initial training included exposure to a simulated altitude of 25,000 feet with a personnel hypoxia experience at that altitude (Type I). As well students experienced a slow decompression from ground level to 18,000 feet (Type IV) to simulate a slow decompression from 8,000 to 25,000 feet while reducing the risk of decompression sickness. As not all initial students knew what aircraft type they would eventually fly some underwent all four chamber exposures.

4.2 Continuation Training
As with initial training, altitude chamber training for continuation courses varied by aircraft type. Ejection seat aircrew underwent a simulated ascent to 43,000 feet with a personal hypoxia demonstration at 30,000 feet (Type II) and a rapid decompression from ground level to 10,000 feet (Type III). However, contrary to STANAG 3114, this training was only done every nine years. Every three years, fixed wing pressurized aircrew underwent a slow decompression from ground level to 18,000 feet (Type IV) while using their appropriate oxygen equipment. Also contrary to STANAG 3114, these students did not take part in personal hypoxia demonstrations. Fixed wing unpressurized and

rotary wing aircrew did not undergo altitude chamber training as part of their continuation training. Therefore following initial training only those aircrew flying ejection seat aircraft repeated personal hypoxia demonstrations and then only every nine years.

5. CANADIAN PROGRAMME REVIEW

In 1990 Canada began a review of its Aeromedical Training Programme including areas such as the relevancy, frequency and categories of training, as well as the health risks aircrew were subjected to as a result of altitude chamber exposure. A survey of Canadian Forces aircrew showed that most were happy with the content of training and felt that only minor alterations should be made to the frequency of training (2).

Following this initial review it was decided that there would be no changes to the academic portions of the course, but that classroom subjects would be updated as required. It was also identified that certain subjects which are mandated by STANAG 3114 such as survival and first aid were not included as part of the aeromedical training syllabus but were provided through other courses.

As for the frequency of training, it was decided that a five year cycle would be sufficient to ensure adequate cognitive retention of the material taught. Additionally it was felt that this five year cycle would mesh better with current posting and training cycles, making it easier to obtain the necessary training and to maintain currency.

Once the academic content and the frequency of the academic training were established, the need for altitude chamber training and the frequency of this training were reviewed. There was no question that altitude chamber training including a personal hypoxia experience was necessary during initial training. The altitude chamber exposure allows realistic training in the operation of oxygen equipment as well as confidence in that equipment. It also allows individuals to experience their personal hypoxia symptoms and to react appropriately to the simulated emergency. To establish the frequency of continuation altitude chamber training it was necessary to determine if hypoxia was a problem in Canadian Forces aircraft and, if so, in which aircraft types.

5.1 Inflight Hypoxia Incidents

Canadian Forces Medical Orders require that all aeromedical incidents investigated and reported by a Medical Officer (3). This same publication defines aeromedical incidents as any incident that occurs between "engine-on" and "engine off" where the pilot, navigator, flight engineer, air observer or jet passenger is injured or suffers a medical problem (3). Therefore, by regulation, hypoxia must be investigated and reported. To quantify the hypoxia problem in Canadian Forces aircraft a review of all aeromedical incidents reported during the period May 1986 to May 1992 inclusive was conducted. As well an assessment was made as to whether additional training or personal hypoxia experiences would have altered the frequency of incidents or their final outcome. The review of aeromedical incidents identified a total of ten hypoxia episodes during the entire period (Table 1). The small number of hypoxia incidents made any statistical correlations irrelevant. However, it must be emphasized that in none of these incidents was there loss of aircraft control and with the exception of one individual who went unconscious all the individuals recognized their hypoxia symptoms.

Based solely on the review of the investigative reports of aeromedical incidents it was impossible to determine what effect recurrent personal hypoxia experiences in an altitude chamber had on the aircrew's ability to recognize hypoxia symptoms in flight and react appropriately.

5.2 Decompression Sickness Incidents

Since the benefits of altitude chamber training could not be clearly established by reviewing incident reports it was decided to review the risks involved in exposing personnel to reduced ambient pressure. To accomplish this a review of the incidence of Decompression Sickness in Canadian Forces altitude chambers for the period 1987-1992 was conducted. The study found that, of the three aeromedical training facilities, one had no cases of decompression sickness and one had no staff

cases but did have a rate of 3.2 cases per thousand exposures for students on 25,000 foot profiles. However at the third facility the incidence of Decompression Sickness was significant with a rate of seven cases per thousand exposures for students and 7.9 cases per thousand exposures for staff on 25,000 foot profiles. For the 43,000 foot profiles the rates were 11.3 cases per thousand exposures for students and 10.3 cases per thousand exposures for staff (4). Although this anomaly remains unexplained, the high incidence of DCS at one unit did raise significant concerns that the risk of altitude chamber training outweighed the benefits in terms of reducing inflight hypoxia incidents.

6. NEW CANADIAN PROGRAMME

As a result of the review begun in 1990 a new Canadian Forces Aeromedical Training Programme was developed and implemented in September 1993 with the regulations for the new programme being promulgated in the Canadian Forces Manual of Aeromedical Training (5).

The most significant changes to the programme are in the frequency of the academic and practical training and in the type of practical training that is required on continuation courses. In addition the new programme has reduced the number of aircrew aeromedical training categories to three, from the previous four, with the amalgamation of the fixed wing unpressurized and fixed wing pressurized categories. No significant changes were made to initial training, and the classroom portions will continue to include the same academic subjects with the content of the lectures being updated.

Under the new policy Canadian Forces aircrew will undergo continuation aeromedical training every five years. This training, regardless of aircraft type, will consist of only academic instruction. Practical training for ejection seat and other fixed wing aircrew will be conducted every second continuation course and will consist of exposure in an altitude chamber to a simulated altitude of 43,000 and 25,000 feet respectively. As part of these chamber exposures students will take part in personal hypoxia demonstrations at simulated altitudes of 30,000 and 25,000 feet respectively. Rotary wing aircrew will not be required to undergo any altitude chamber training as part of their continuation courses.

The new Canadian Aeromedical Training Programme deviates from STANAG 3114 in the frequency and type of practical training provided on continuation courses. The decision to do this was based on the Canadian experience and may not be appropriate for all nations.

7. ALTERNATIVE PROGRAMMES

A number of other NATO countries besides Canada are reviewing their Aeromedical Training Programmes. In the United States for example, the Navy has conducted a major review of their programme and is currently in the process of evaluating a new method of providing continuation aeromedical training.

Further, countries outside NATO have aeromedical training programmes which can be examined to find valuable methods for improving NATO aeromedical training programmes. Australia, for example, currently has a practical night vision training session that may be extremely valuable in any updated programme.

7.1 U.S. Navy Review

The U.S. Navy continuation aeromedical training programme underwent an intensive review in 1994 that identified many areas for improvement (6). The findings of this review are significant in that the U.S. Navy closely follows the aeromedical training programme specified in STANAG 3114.

One element of the U.S. Navy programme identified as needing to be changed was the requirement to repeat altitude chamber training. The review classifies altitude chamber training as experiential learning; the aim is to have the student experience gas expansion and hypoxia. As such it should not have to be repeated following an initial exposure. The review goes on to indicate that if the desired result is to have the student remember a list of hypoxia symptoms then an altitude chamber exposure is unnecessary and

the training could be better accomplished in a classroom.

The review also found that the frequency of refresher training should be changed. Since most of the items involved in aeromedical training are cognitive in nature the retention of this knowledge will be short. Therefore to ensure retention of the material the review recommends that ongoing refresher training take place at squadron level between formal continuation courses.

As does STANAG 3114, the review of the U.S. Navy programme recommended that students be tested on completion of training. However, unlike the STANAG that recommends a written test, the review recommended a group-based testing method. The example given was of a small group being " given actual case histories of aviation physiology problems to review, determine the concern and provide the necessary corrective action" (6).

7.2 U.S. Navy Trial Programme
In an attempt to improve their current continuation aeromedical training the U.S. Navy is running a trial wherein aeromedical training is incorporated into flight simulator training. This method of continuation training encompasses many of the recommendations of the previously described programme review and was first demonstrated using the U.S. Navy V-22 simulator.

In this demonstration various aeromedical scenarios were introduced into standard flight simulator missions and the crews were required to recognize the problem and eliminate it or reduce its effects while still flying the simulator mission. For example, a crew could be given a mission to pick-up a commando unit on a beach and airlift it to a landing site at an elevation of 6,000 feet on the far side of a ridge line with an elevation of 10,000 feet, in hostile territory at night. The crew would brief for the flight, enter the simulator and begin the mission. As with normal simulator missions aircraft emergencies would be encountered during the flight; in addition, a physiological emergency would be presented to the crew. This could be done by having the crew chief notify the pilot that one of the commandos was experiencing pain in both knees. The pilot would then have to assess the emergency and decide whether or not to proceed with the mission. To make this decision the pilot would have to know enough about decompression sickness to realize that, as a commando, the individual with pain in both knees may have been diving recently and may therefore be suffering from decompression sickness even at the altitude of the mission. A scenario such as this not only tests the pilot's knowledge of aeromedical subjects but his decision-making abilities and crew coordination as well.

7.3 Australian Night Vision Training
The Royal Australian Air Force aeromedical training programme conducts night vision training during an exposure to a simulated altitude of 15,000 feet. Students sit in an altitude chamber, connect to communications and oxygen, and conduct a test of these systems. Once this is completed the students drop their oxygen mask from their face and await the ascent to altitude. Using infrared cameras to monitor the internal safety, chamber lighting is extinguished and viewports are occluded so the chamber is in total darkness. The chamber altitude level ascends to 15,000 feet and the instructor begins his lesson on night vision. This instruction includes all aspects of night vision including many practical demonstrations. One of these demonstrations involves the students attempting to read dimly lit flight instruments placed at one end of the chamber after a period of time at 15,000 feet. To complete the lesson students replace their oxygen masks and again attempt to read the dimly lit flight instruments. Most if not all students find themselves able to read the instruments once back on oxygen thereby demonstrating the significant effect even mild hypoxia can have on night vision.

8. THE FUTURE
In the future, aeromedical training programmes will have to demonstrate that they are effective and beneficial if they are to survive. Additionally, with greater demands being placed on the time aircrew have available for

all types of training, aeromedical training will have to become more integrated into the overall flying training programme.

8.1 Results Measurement

If, like Canada, other countries are going to change their aeromedical training programmes, it is essential that techniques be developed that can measure the training effect on flight safety and aircrew performance. Once measurement techniques are developed they should be used to assess current aeromedical training programmes to determine what effect they are having. Based on the results of this assessment, areas of the programme that require improvement could be identified and changed. The effects of these changes could then be assessed to determine if they are appropriate or if they have the desired effect on the training outcome.

8.2 Simulators

The U.S. Navy trial is demonstrating that aeromedical training can be conducted during regular flight simulator sessions. Unfortunately, this method of conducting aeromedical training is limited by the capability of current flight simulators. It is not possible using current flight simulators to allow students to experience the effects of changes in altitudes or acceleration forces. A device that would allow aircrew to experience the full range of physiological effects that can be encountered during flight, while flying a simulated mission, would maximize the training benefits. Such a device would also allow the integration of aeromedical training into current flight simulator missions thereby reducing the time required to learn how to safely operate aircraft in a physiologically hostile environment.

9. CONCLUSIONS

The Canadian Aeromedical Training Programme has recently undergone significant changes. Some of these changes were based on experience and others, due to a lack of hard evidence, were based on the judgement that they were appropriate. Other countries are also reviewing their aeromedical training programmes and looking for new or different ways to provide the necessary academic training at the correct frequency using the best methods possible. The U.S. Navy has completed an extensive review of its programme and is now looking at ways to improve, and the Australian night vision training session uses innovative ideas to accomplish training

For whatever reason programmes are being evaluated and modified, it seems inevitable that there will continue to be changes to aeromedical training in the future. To ensure that these changes are appropriate and that they improve flight safety, it is essential that measurement tools be developed to assess current programmes and to determine the changes to the programmes.

Finally, it would seem appropriate, in the interests of international standardization of aeromedical training in the future, to revise the terms of STANAG 3114.

10. REFERENCES

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3. Canadian Forces Medical Orders Volume 2, National Defence A-MD-175-002/AG-001, Ottawa, Ont., Canada, 1977

4. Glass, K.C. and Brooks, C.J., "Incidence of Decompression Sickness in Canadian Forces Altitude Chambers", presented at the Aerospace Medical Association Annual Meeting, San Antonio, Texas, May 1994

5. Canadian Forces Manual of Aeromedical Training, National Defence A-MD-214-001/PT-001, Ottawa, Ont., Canada, 1994

6. Training Review Report for Naval Physiology and Water Survival Training Programmes, Enzian Technology, Inc., Orlando, Florida, USA, September 1994

Aircraft Type	1986	1987	1988	1989	1990	1991	1992
CT 133	-	-	-	-	1	-	1
CT 114	1	-	-	-	-	1	-
CC 115	1	1	-	1	-	-	-
CF 118	-	-	1	-	-	-	-
CP 121	1	-	1	-	-	-	-
Total	3	1	2	1	1	1	1

Table 1 Reported Inflight Hypoxia Incidents 1986-1992

Centrifuge Training in the Canadian Forces: A Review of the First Six Years' Experience

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1. SUMMARY

In the late 1980s, the Canadian Forces developed and implemented a centrifuge training program intended to enhance the preparedness of its aircrew for the G-stress of modern fighter aircraft. In the six years from 15 June 1989 until 25 May 1995, 439 personnel attended 97 serials of this one-day course. Although a rigid performance standard was not set, aircrew from various CF pilot populations completed the target profile with success rates ranging from 61-83% (the more experienced fighter pilot groups doing better). The lessons learned in this first six years have paved the way towards a new program, with broader mandatory target population, provisions for refresher training, and G-tolerance improvement for those unable to complete the target profile.

2. INTRODUCTION

The Canadian Forces (CF) had long recognized the importance of preparing its aircrew for the High Sustained G (HSG) environment, and had considered centrifuge training as an adjunct, but the need became more pressing in the early '80s with the advent of its CF-18 'Hornet' fleet. The latter was chosen as a replacement for aging CF-5 'Freedom Fighter', CF-101 'Voodoo', and CF-104 'Starfighter' fleets, and was recognized as being capable of imposing far higher G-stress onset rates, levels, and durations than any of its predecessors.

The experience of other air forces in implementing similar modern HSG-aircraft led some to develop centrifuge training programs, whose reputations quickly supported the idea that such training might be important for the CF to pursue. In the mid-1980s, the only human centrifuge at the CF's disposal was the WWII-vintage eight-foot arm facility affectionately known as 'the Pumpkin'. This facility, although it could boast a variety of firsts (e.g., it was the first such facility in the British Empire), and a long and distinguished career, was entirely incapable of simulating the HSG environment of the CF-18.

Accordingly, alternatives in other nations were explored. Since the first operational CF-18 Squadrons were devoted to service with 1 Canadian Air Group (1 CAG) in Europe, it made sense to seek this training where it was needed most. In November, 1985, two CF pilots underwent centrifuge training at the RNLAF facility in Soesterberg, the Netherlands. Their visit confirmed the impressions of many that high priority should be given to implementing similar training. Although the RNLAF program served the CF's early needs ideally, this was only an interim measure. Plans for a new Canadian centrifuge research facility to replace 'the Pumpkin' were already underway, and agreements were forged that would devote a portion of this new facility's time to training. The Defence and Civil Institute of Environmental Medicine (DCIEM) centrifuge was completed in Fall, 1988, and made possible a CF centrifuge training program.

3. THE APPROACH

Discussions about the approach a CF HSG training program should take, dated from the initial rides in the RNLAF facility in 1985. Consensus was sought on a variety of important issues of training strategy. Perhaps the most contentious was settled in 1987 by the CF Chief of Air Doctrine and Operations with the following edict:

"It should be emphasized that the centrifuge should be for training purposes only and not for selection of aircrew for the high performance role"

This paved the way to a program aimed at enhancing, in a non-threatening environment, the familiarity of aircrew with hazards of HSG and the strategies used to combat them, without the fear of a 'pass/fail' disposal hanging over attendees' heads. Such a strategy was particularly wise since all of the initial student population was already trained and experienced in the fighter environment, and therefore far from being naive enough about the hazards of the HSG environment to warrant any consideration of removing them from it based on the results of a single centrifuge session. The program finally agreed upon[1] and implemented[2] entailed one day training conducted at DCIEM, and consisted of classroom sessions including discussions of the physiology of HSG, G-induced Loss of Consciousness (G-LOC), and countermeasures such as the G-suit and the Anti-G Straining Maneuver (AGSM). Centrifuge sessions that followed consisted of the runs outlined in Table 1.

Paper presented at the AMP Symposium on "Selection and Training Advances in Aviation", held in Prague, Czech Republic, in May 1996, and published in CP-588.

TABLE 1: CENTRIFUGE RUNS IN CF HSG TRAINING PROGRAM

Run	Description	Onset Rate	Remarks
GOR	Gradual Onset Rate	0.1G/sec	Initially relaxed until a symptom of visual loss occurs, then continuing using AGSM until tolerance or a maximum of 9G; G-suit disconnected
ROR 6/30*	Rapid Onset Rate to 6G for 30 sec	≥1.0 G/sec†	G-suit connected; profile enables practice of AGSM for prolonged time under moderate G-stress
ROR 8/15*	Rapid Onset Rate to 8G for 15 sec	≥1.0 G/sec†	G-suit connected; 'Target Profile' defining performance objective
SACM	Simulated Air Combat Manoeuvre	various	Optional profiles from which those completing target profile, who wish more practice, may choose

* -In July, 1990, these runs were substituted for ROR 5/30 (to 5G for 15 sec) and ROR 7/15 (to 7G for 15 sec), respectively, for attendees not normally flying aircraft equipped with G-suits

† -In December, 1991, an upgrade of the centrifuge transmission was completed enabling onset rates of up to 3.6 G/sec, which were then used for ROR profiles

Some 501 positions in the CF were identified as requiring HSG training[1]. These consisted of pilots flying CF-18, CF-5 (retained in service until 1995, while CF-101 and CF-104 were retired in the early 1980s), trainees on these aircraft, and instructors on the CT-114 'Tutor' (used in Basic Jet Training). Although there was much support for a 'mandatory' approach to this training and for provisions for refresher and remedial training, policy defining these was never promulgated, so commanders had considerable discretion as to who needed this training and when they needed it (consequently only a handful of pilots ever returned for refresher or remedial sessions). Reporting of attendees' performance would take 'has-attended' form only, and formal rating of course performance were not to be recorded.[2] While course reports did comment on the runs an attendee either "completed" or "...was exposed to...", no reference was made to G-LOC or to their performance on any target profile. Although details of attendees' runs were not reported to their Commanders, the information was stored in a database and video-tapes were made of each run (largely as an adjunct to post-run debriefs). Should concerns subsequently arise about an attendee's performance in the centrifuge (for example, during accident investigation) and to enable population analysis, it was agreed that such records would be highly desirable.

Considerable debate took place over the issue of physiological monitoring, in particular, the need for electrocardiography (ECG) in centrifuge riders. On the one hand, DCIEM and the rest of the medical community had keen interest in the ECG findings of aircrew in the centrifuge (both from the patient-welfare and research points of view); on the other, the operational community was understandably hesitant. One Commander warned:

"*...if this monitoring is misused just once to create a medical brushfire, aircrew will become suspicious and resentful...*"

Indeed such caution seemed warranted: the fear of unscrupulous groundings arising from ECG findings of unknown clinical or operational significance had led the operational communities of some other air forces to forbid the ECG monitoring of their aircrew. In the end, however, DCIEM was able to gain enough support for this monitoring (and for flight surgeon presence during the runs) to allow it to be implemented.

Other issues that were raised included the need for closed-loop control and outside world picture (CLC/OWP; where there is 'man-in-the-loop' control of the centrifuge by the gondola rider), as well as for exposures to negative-G. Although many agreed these could be important elements of future training, no one felt strong enough about them to advocate (much less allocate) the extra funds that would be required to implement them. As a result, the DCIEM centrifuge and the CF HSG Training Program entailed only computer-controlled profiles.

Canadian input to development of the NATO STANAG on HSG training for aircrew (STANAG 3827) took place concurrently with that of the CF HSG Training Program. Accordingly, these were made consistent with each others' provisons.

4. THE RESULTS

The DCIEM centrifuge facility (which is described elsewhere[3]) was completed and man-rated in fall, 1988 and a test serial of the CF HSG Course took place in January, 1989. In this, it was agreed that the approach was sound and so training schedules were drawn up, with the first formal serial of the course taking place 15 June 1989 for six CF-18 pilots.

From 15 June 1989 until 25 May 1995 (the first six years), 439 students attended 97 serials, and pertinent results extracted from the CF HSG Course database are presented in Table 2. Some of the highlights of thereof are discussed below.

TABLE 2: STATISTICS ON CF HIGH SUSTAINED G COURSE - JUN 89 - MAY 95

	Total [1]	32U (Pre-Wings)	Qualified Pilot MOC 32 [2]	Non-F-18/ F-5 Post Wings [2, 3]	Actively Flying F18/F5 [2]
Attendees:	439	28	400	236	164
Median Flying Time	1302	192	1414	1190	1738
Average Hrs CA[4]	496	0	541	626	420
Mean Age	28	26	28	27	30
PERFORMANCE ON CORE PROFILES (GOR, R5 or 6/30, R7 or 8/15) [7]					
Completed R7/15 [5]	102	7	89	88	1
Completed R8/15 [5]	195	2	192	57	135
Total completing target profile (R7, 8/15) [7]	297 (68%)	9 (32%)	281 (70%)	145 (61%)	136 (83%)
Total NOT completing target profile[7]	142 (32%)	19 (68%)	119 (30%)	91 (39%)	28 (17%)
Average $GOR_{relaxed}$ [8]	4.2	4.2	4.2	4.2	4.2
Average GOR_{max} [8]	7.1	6.9	7.1	7.1	7.2
Average AGSM (GOR_{max} - $GOR_{relaxed}$) [8]	2.9	2.7	2.9	2.9	3.0
Experienced G-LOC during course [5]	94 (21%)	14 (50%)	78 (20%)	61 (26%)	17 (10%)
G-LOC once [5]	65	62	10	51	11
G-LOC twice or more [5]	23	17	4	14	3
G-LOC, then completed target profile (R7/15, R8/15) [6]	9	9	0	5	4
PERFORMANCE ON OPTIONAL (SACM) PROFILES					
Attempted at least one	76	3	73	37	36
Completed at least one	50	2	49	23	26
G-LOC on optional profile [5]	7	1	6	3	3

ABBREVIATIONS

GOR	Gradual Onset Rate profile to limit of attendee's tolerance
ROR	Rapid Onset Rate profile
R5 or 6/30	ROR profile to either 5 or 6 G, sustaining this level for 30 sec
R7 or 8/15	ROR profile to either 7 or 8 G, sustaining this level for 15 sec
SACM	Simulated Air Combat Manoeuver: one of three profiles of rapidly varying G levels and durations
AGSM	Anti-G Straining Manoeuver

Footnotes

1 Includes CF and Foreign Exchange Pilots, untrained pilots and non-pilots (i.e. Aeromed Techs, Navigators, etc)

2 Includes Foreign Exchange Pilots (five in total)

3 Includes CF18/CF5 pilots who were flying other aircraft types at the time of the course

4 CA = Current Aircraft

5 Includes students who experienced G-LOC during off-load and during SACM

6 Includes students who experienced G-LOC during off load in either of first two profiles (GOR or R5/30 or R6/30)

7 In late 1990, the target profile R7/15 was introduced for pilots not normally using G-suits. Prior to this, the target profile for all attendees was R8/15.

8 This reflects performance on the INITIAL Gradual Onset Rate (GOR) profile - no information about the efficacy of attendees' AGSMs obtained AFTER centrifuge sessions

Although the course was primarily intended for pilots of the CF's high-performance aircraft (CF-18 and CF-5), as the portion of these personnel having completed the training rose, more slots became available for others. Not only were instructors in the CT-114 "Tutor" given centrifuge training, but also were other more junior aircrew (even some before 'Wings' qualification). The rationale for diversifying the target population arose from a 1986 survey (not completed until 1988) that sought to define the incidence of G-LOC in all CF aircrew[4]. This study found that only 13% of G-LOC episodes had occurred in the CF-18 (but it should be noted this aircraft had only been operational for a few years at this time), while the CT114 and other similar aircraft accounted for 82% of all episodes. Furthermore, 57% of all G-LOC occurred during wings training. Accordingly, attendees of the CF HSG Course became increasingly diverse after early 1991.

The incidence of G-LOC during the CF HSG Course was 78/400 (20%) in qualified CF pilots, 61/236 (26%) in non-F18/F5 pilots, and 17/164 (10%) in actively-flying F18/F5 pilots. This seems to support what is intuitive: HSG experience appears to reduce G-LOC rates in the centrifuge. A policy was established early in the Program to limit to two the number of G-LOC episodes an attendee was permitted daily. This meant that trainees were removed from the centrifuge after their second G-LOC episode in a day.

The rate of successful completion of target profiles was 297/439 (68%) in qualified CF pilots, 145/236 (61%) in non-F18/F5 pilots, and 136/ 164 (83%) in actively-flying F18/F5 pilots. Conversely, the rate of failure to complete target profile is 142/439 (32%) in qualified CF pilots, 91/ 236 (39%) in non-F18/F5 pilots, and 28/164 (17%) in actively-flying F18/F5 pilots. This was to some the most alarming statistic: it would appear that 17% of F18/F5 pilots are unable to complete the target profile in the CF HSG Course.

During the Gradual Onset Rate (GOR) Run, attendees were given the chance to familiarize themselves with their personal visual end-point symptoms of impending G-LOC (which in our experience differ considerably amongst individuals). The visual end-point levels of G-tolerance, both relaxed (mean=4.2G) and straining (mean = 6.9-7.2G), remained remarkably constant across populations of attendees. This means that experience does not appear to affect significantly one's resting or straining G-tolerance.

Other findings extracted from the database (but not appearing in Table 2) include that 224/432 CFHSG attendees underwent training on the DCIEM centrifuge prior to its upgrade in Fall, 1991 (see Table 1). This means that they have been trained under the lower +Gz-onset rate (of less than 1.0 G/sec) than those who were trained after the upgrade (208/432), when onset rates of almost 4G/sec became possible.

There were no adverse medical incidents (ie, those involving significant medical intervention or sequellae). Of particular aeromedical interest, an extensive review of the ECG findings is currently underway. Preliminary results suggest that although these are very common, no finding was ever of sufficient concern to warrant any flying or other operational restriction. Furthermore, although ECG criteria mandating run termination were initially quite stringent, after the first year of the program, no run was ever terminated solely on the basis of ECG findings.

5. LESSONS LEARNED

The foregoing results were reported to the CF's Air Command in August, 1995 and they sparked predictable interest, particularly surrounding the 17% unsuccessful completion rate of CF-18/CF-5 pilots. Such concerns were reinforced by a tragic CF-18 accident in July 1995 where G-LOC was identified as a probable cause factor, and the pilot of the accident aircraft had been unable to complete the target profile in his centrifuge training session 29 months before (he was, however, at this time only flying CT-114).

This experience led to the call for a mandatory HSG training program with mandatory performance objectives for high-risk populations and refresher training. Although there was sound rationale for the initial 'has-attended' approach of the Program, perhaps the time had come for a more rigorous strategy. A mandatory standard linked to a remedial program (avoiding the 'pass/fail' stigma) had long been considered[5], but now seemed more prudent and important.

Training lessons learned have included the need to stress importance of an initial deep breath when AGSM is started (many attendees had difficulty completing target profiles when they began their AGSMs from end-expiration), and the difficulties displayed by many in keeping a constant leg strain while cycling respirations. Problems with the latter rather unnatural action - whose proper performance is crucial to an effective AGSM - are sometimes difficult to detect, even with the benefit of overhead cameras. Measures such as electromyographic monitoring for thigh muscles are being considered to facilitate critique of attendees' AGSMs.

The curriculum of the classroom sessions has remained flexible so that new training aids (videotapes, etc) can be introduced as they become available, and so that discussion of new issues can be incorporated as they appear. An example of the latter is the growing emphasis that has been placed on the importance of negative-to-positive G-transitions ('Push-Pull Effect') since understanding of this phenomenon has improved[6].

6. THE FUTURE

In response to a request from the CF's Air Command, DCIEM developed proposals for revising the CF HSG. These revisions were implemented Spring, 1996 and at the time of writing several serials of the "New Course" had been conducted. Key elements of the revision include a mandatory "PASS/NOT YET PASSED" approach to a common performance objective (7G/15sec without G-suit) for all 'at-risk' aircrew (currently defined as those regularly exposed to more than 4G) with the enlisting of unsuccessful attendees in a G-Tolerance Improvement Program (G-TIP). This offers measures intended to improve AGSM effectiveness through practice exercises, continued flying duty (though with an operational flying restriction limiting G-exposure to less than 4G), aeromedical evaluation where indicated, and follow-on attendance on HSG Course within six months. Those still unable to complete target profiles thereafter will have their cases reviewed by Air Command. Successful attendees will be required to have refresher training after five years or after a layoff that would require return to an operational training unit.

The role of physical fitness training in the G-TIP remains unclear, largely because of a lack of consensus over the effectiveness of any exercise Program at improving G-Tolerance. As more evidence becomes available, this stance will be reviewed.

Discussion continues as to the need for improving the DCIEM centrifuge facility to incorporate more rapid G-onset rates, CLC/OWP, and negative-G transition capabilities, but the recent shelving of a centrifuge replacement program because of budgetary cuts makes these improvements anything but imminent or likely.

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ENTRAINEMENT DES PILOTES D'ESSAIS A LA SURPRESSION VENTILATOIRE SOUS FACTEUR DE CHARGE

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RESUME

La protection anti-G par la surpression ventilatoire est actuellement en cours d'évaluation dans le cadre du programme Rafale. Avant l'utilisation de ce moyen de protection en vol réel, un entraînement des pilotes en centrifugeuse a été préconisé. Cet entraînement a pour but de démontrer aux pilotes le gain de tolérance apporté par la ventilation en pression positive et de les sensibiliser aux particularités ergonomiques et physiologiques de ce type de protection anti-G. Il est également destiné à vérifier le fonctionnement nominal des équipements de protection personnels des pilotes.

Dix-huit pilotes d'essais ont été soumis à trois profils d'accélération. Pour le premier profil, ils ne disposaient d'aucun équipement anti-G. Pour les profils suivants, ils portaient un pantalon anti-G, soit seul (deuxième profil) soit associé à un équipement de surpression ventilatoire (troisième profil).

Cet entraînement a permis aux pilotes d'évaluer le réel intérêt de la surpression ventilatoire sous haut facteur de charge pour leur protection physiologique et leur confort. Il a permis par ailleurs de les sensibiliser sur la nécessité d'un ajustement rigoureux des

équipements de tête et d'une "éducation ventilatoire" particulière pour l'obtention d'une protection anti-G correcte.

1. INTRODUCTION

Les avions de la génération actuelle M 2000, F16, F18 sont caractérisés par une capacité à soutenir des facteurs de charge élevés (> 7 +Gz) soutenues (> 30s) et rapidement installées (> 8G/s).

Cet environnement biodynamique est contraignant pour les pilotes et ceux-ci n'arrivent à le surmonter que si des mesures de protection ont été prises. Ces mesures sont essentiellement représentées sur le F16 par l'inclinaison du siège. Cette inclinaison amène un gain de protection théorique d'environ 1G. Pourtant, plusieurs pertes de connaissance sous facteur de charge ont été à l'origine d'accidents aériens sur cet avion lors des cinq premières années en service. En effet, cet avion doté d'une motorisation puissante est capable de maintenir presque de façon infinie (réserve de carburant non comprise) des accélérations élevées et

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soutenues qui fatiguent particulièrement les pilotes.

De plus, il est doté d'un manche latéral à effort et donc sans déplacement. Les pilotes ayant été formés sur des avions ayant des manches centraux et à déplacement sont parfois surpris par ce type de commande. Ils se soumettent alors de façon brutale à des accélérations très élevées qui sont d'autant moins bien supportées que les pilotes sont fatigués par les accélérations qu'ils ont subies auparavant. C'est ainsi que des pertes de connaissance sans manifestations prodromiques surviennent.

Pour réduire ces pertes de connaissance, un entraînement en centrifugeuse a été mis en place dans de nombreux pays de l'OTAN. Cet entraînement a deux buts, un endoctrinement à la réalisation correcte des manoeuvres anti–G et une formation aéromédicale. Il n'en reste pas moins que d'autres mesures ont été prises à titre correctif sur le F16 ou à titre préventif sur le Rafale, l'EFA et le F22. Il s'agit de l'amélioration du pantalon anti–G et de la surpression ventilatoire.

La surpression ventilatoire s'est imposée comme une méthode de choix pour la protection des équipages d'avions de combat. La tolérance des équipages est augmentée en niveau et en temps. En effet, le gain de tolérance est d'environ 2,5 G et le temps de tolérance est multiplié par deux. La loi de surpression retenue en France pour le Rafale est de 1.8 kPa/G à partir de 4 +Gz avec une valeur maximale de 9 kPa.

D'autres lois , débutant à partir de 6 +Gz pour valeur maximale de 9 kPa aboutissent à des valeurs maximales inférieures (7 kPa) ont été étudiées et il n'a pas été mis en évidence de différence de tolérance. Après avoir fait l'objet de toute une série d'expérimentations en laboratoire, la surpression ventilatoire a été expérimentée sur M200 d'une part et sur Rafale d'autre part. Les pilotes d'essais impliqués dans cette évaluation ont subi un entraînement spécifique en centrifugeuse. Les modalités de cet entraînement fait l'objet de cette présentation.

2. OBJECTIFS DE L'ENTRAINEMENT

L'entraînement en centrifugeuse des pilotes d'essais a plusieurs objectifs. Il s'agit :

- d'un rappel des effets des accélérations sur l'être humain avec la connaissance précise des symptômes et des effets physiologiques des accélérations, les mécanismes impliqués dans la tolérance et les facteurs pouvant agir sur cette tolérance

- d'une familiarisation des pilotes avec l'ensemble des équipements de vol imposés par la surpression ventilatoire ainsi que leur adaptation. Cette séance d'entraînement est aussi dédiée à l'ajustement des équipements (casque et masque en particulier) à la morphologie des pilotes.

- d'un endoctrinement des pilotes à la réalisation correcte des manoeuvres anti–G afin qu'ils puissent améliorer leur tolérance aux accélérations

- d'une accoutumance des pilotes à la surpression ventilatoire, de leur permettre de respirer de façon normale, de pouvoir effectuer des manoeuvres anti–G et de parler dans ces conditions.

3. METHODOLOGIE

L'entraînement en centrifugeuse à la surpression ventilatoire nécessite un ensemble de matériel d'entraînement dont une centrifugeuse, des équipements de vol et s'effectue selon un protocole défini préalablement.

3.1. Matériel

La centrifugeuse humaine du Laboratoire de Médecine Aérospatiale est utilisée pour cet entraînement. Elle comporte un bras de 6 mètres au bout duquel la nacelle humaine est installée (La centrifugeuse peut être dotée de

différents types de nacelle). L'inclinaison du dossier du siège et la position des palonniers sont similaires à celles de chacun des aéronefs. Un système vidéo et de liaison phonique, avec enregistrement permet de suivre le pilote entraîné et d'enregistrer les informations. (Cet enregistrement est ensuite utilisé à des fins d'enseignement.)

Le pilote ne commande pas le profil d'accélération car la centrifugeuse est en commande manuelle.

La nacelle dispose d'un test de champ visuel selon l'axe horizontal et le pilote a un manche en position latérale droite pour signaler l'importance de son champ visuel.

Le manche de test du champ visuel est doté d'un bouton d'alarme qui, lorsqu'il est pressé fait entendre une sonnerie. Cette alarme pourra éventuellement être utilisée si le pilote demande à arrêter la centrifugation.

L'entraînement est effectué sous l'autorité d'un médecin, spécialiste du domaine mais pour éviter tout malentendu, aucune mesure physiologique (électrocardiogramme, mesure de la pression artérielle ou de débit sanguin,) est effectué.

3.2. Equipement de vol

Les pilotes sont dotés de leur équipement de vol. Cet équipement comprend un casque GUENEAU 458 doté d'une vessie occipitale et d'un masque ULMER 88 doté d'un joint étanche. La vessie et le joint se gonflent à la même pression que la pression établie dans le masque.

Le pilote est d'autre part équipé du pantalon anti-G ARZ 830 qui est un pantalon à vessie étendu et du gilet GP 2000 comportant une vessie de contre pression thoracique. Le pilote d'essai porte le pantalon anti-G et la veste de contre pression sur la combinaison de vol

Le casque et le masque font l'objet d'une personnalisation effectuée de façon successive. La personnalisation consiste à mettre en place une patte de caractéristique différente pour le casque et le masque mais permettant un ajustement le plus adapté à la morphologie de chacun. Ce sont ces équipements qui sont utilisés en vol.

Les équipements de vol sont alimentés en oxygène par un ensemble électronique "régulation valve anti-G" de laboratoire. Cet ensemble de laboratoire est similaire sur le plan technologique à l'ensemble de régulation utilisé en vol. Il dispose de boutons permettant d'ajuster les lois de pression dans les équipements de façon similaire à celles qui ont été tenues pour les essais en vol.

La loi de pression dans le pantalon est de 7 kPa/G à partir de 2 +Gz jusqu'à la valeur maximale de 50 kPa. La loi de surpression ventilatoire est de 1.8 kPa/G à partir de 4 +Gz jusqu'à la valeur maximale de 9 kPa.

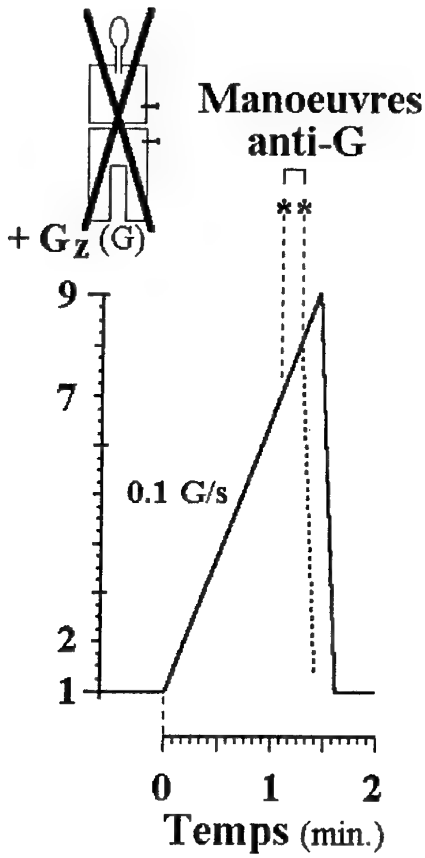
3.3. Protocole d'entraînement

La protocole d'entraînement défini préalablement se déroule sur une journée pour quatre pilotes d'essais. Il comporte la phase initiale de formation aéromédicale des pilotes d'essais d'une durée d'une heure, la phase de personnalisation du casque et du masque, la phase de test d'étanchéité des équipements et les profils d'accélération proprement dit.

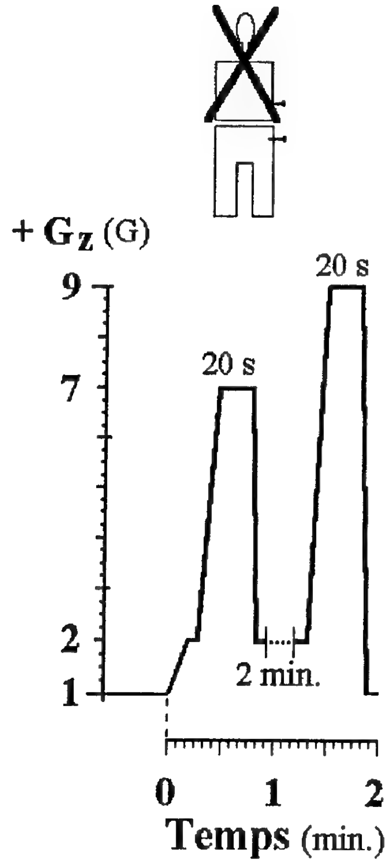
Les tests d'étanchéité du pantalon et de la surpression ventilatoire s'effectuent dans la nacelle de la centrifugeuse avec des valeurs respectives de pression de 10 et 9 kPa. Si l'étanchéité du masque n'est pas obtenue, la personnalisation du masque est effectuée de nouveau.

Les profils d'accélération sont répartis en trois phases séparées les unes des autres par un arrêt complet de 10 minutes avec une ouverture de la nacelle de la centrifugeuse. Les pilotes doivent effectuer chacune des trois phases en effectuant le test de champ visuel. La limite de tolérance est fixée à une réduction de 50 % du champ visuel.

La première phase consiste à mesurer la tolérance de chacun des pilotes aux accélérations. Le pilote est équipé de son équipement de protection, mais celui ci n'est pas connecté à l'ensemble "régulation valve anti–G". Il est soumis à un profil de mise en accélération lente à 0,1 G/S. Au cours de cette montée en accélération, le pilote doit atteindre successivement sa limite de tolérance sans puis avec manoeuvre anti–G ou atteindre 9 +Gz. Cette détermination s'effectue grâce au test de champ visuel.



La deuxième phase consiste à soumettre les pilotes à deux plateaux d'accélération successives et élevées séparés d'un plateau d'accélération à 2 +Gz de deux minutes. Le pantalon anti–G connecté à l'ensemble de régulation est alors gonflé. Le pilote effectue des manoeuvres anti–G. Les plateaux d'accélération ont été fixés successivement à 7 et 9 +Gz. Chaque plateau d'accélérations dure 20 secondes et les variations d'accélération sont fixées à 1 G/S.



Les accélérations de la troisième phase sont similaires à celles de la seconde. Par contre, la totalité de l'équipement des fonctionnel. Le pilote bénéficie alors de la surpression ventilatoire. Les manoeuvres anti–G ne sont effectuées que s'il apparaît une sensation d'intolérance aux accélérations.

A l'issue de ces profils d'accélération, les pilotes ôtent leur équipement de vol et sont examinés par un médecin. Ils revoient la cassette vidéo et le médecin commente alors cet entraînement.

4. RESULTATS

L'ensemble des pilotes d'essais impliqués dans l'évaluation de la surpression ventilatoire en vol ont bénéficié de l'entraînement en centrifugeuse.

La première phase établissant un rappel de physiologie des accélérations a reçu un accueil favorable de la part des intéressés.

L'examen médical effectué par le médecin montre, qu'à l'issue de cet entraînement, certains pilotes présentent des pétéchies dans les zones non protégées par les vessies de contre–pression. Ces pétéchies sont particulièrement importante au niveau des chevilles.

Par contre, les pilotes considèrent l'endoctrinement au manoeuvres anti–G comme une amélioration certaine de leur tolérance aux accélérations. Ils estiment avoir bien appris ces manoeuvres, ils sont convaincus de leur efficacité et envisagent de les utiliser au cours de leurs futurs vols.

Par rapport à l'entraînement à la surpression ventilatoire, les pilotes ont été surpris des sensations subjectives induites par cette méthode mais se sont surtout rendu compte de l'amélioration de la tolérance aux accélérations. Le dialogue établi au cours de la centrifugation entre le médecin et le pilote a permis de réduire de façon importante l'inquiétude des pilotes ressentie aux premières bouffées d'oxygène. En ayant reçu la consigne de moduler leurs manoeuvres anti–G, ils ont pu se rendre compte du gain de tolérance apporté par cette méthode.

D'une manière générale, les pilotes d'essais, habitués à s'entraîner sur simulateur avant la réalisation d'un vol d'essais, ont estimé que cette journée d'entraînement avait été beaucoup plus bénéfique que ce qu'ils avaient pensé.

5. DISCUSSION - CONCLUSION

Les vols d'essais effectués pour la surpression ventilatoire ont démontré que non seulement cette méthode améliorait la tolérance aux accélérations mais que les sensations désagréables ressenties en centrifugeuse disparaissent lors de ces vols. En effet, les pilotes préoccupés à conduire leur machine lors de missions de combat aérien ont leur attention centrée sur ces missions et non plus sur les sensations subjectives induites par la surpression ventilatoire.

La surpression ventilatoire sous facteur de charge est une méthode de choix pour la tolérance aux accélérations. L'entraînement en centrifugeuse doit être impérativement mené pour habituer les pilotes à utiliser cette méthode de façon optimale. Cet entraînement a plusieurs objectifs qui sont les suivants.

- Un enseignement de physiologie aéromédicale qui leur permet de comprendre les mécanismes impliqués par cette méthode

- Une familiarisation des pilotes avec l'ensemble des équipements de vol imposés par la surpression ventilatoire ainsi que leur adaptation.

- Un ajustement des équipements à la morphologie des pilotes.

- Un endoctrinement des pilotes à la réalisation correcte des manoeuvres anti–G

- Une accoutumance des pilotes à la surpression ventilatoire et une accoutumance à l'association des manoeuvres anti–G avec la surpression ventilatoire pour utiliser de façon optimale cette méthode.

ADVANCED SPATIAL DISORIENTATION DEMONSTRATOR:
Component, Profile, and Training Evaluation

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SUMMARY

Results of the first experimental evaluation of the Advanced Spatial Disorientation Demonstrator (ASDD) installed at Brooks AFB, TX are described. The ASDD was evaluated by a mix of experienced pilots and novices. Spatial Disorientation (SD) training profiles were programmed into the device in an attempt to induce Type I (unrecognized) and Type II (recognized) SD. Reliable generation of SD illusions and visual/vestibular sensory conflicts on the ground, in a safe environment, can in principle provide training to aircrew to aid in recognizing and coping with SD in flight, and also can be used as an environment to design instrument displays. To that end, the ASDD components, SD profiles, and training potential were evaluated.

1. INTRODUCTION

Spatial disorientation (SD) is a killer! During a two month period in 1995, the United States Air Force (USAF) lost about $85M in flight resources (two aircraft, and two lives) due to SD. These two aircraft losses and mishaps are added to the other 31 aircraft lost and 29 mishaps attributable to SD since 1990, totaling $470M in losses to the USAF. Hindsight seems to indicate these accidents and others like them could have been prevented with some improvements to the flight information displays, but all too often these modifications are either delayed or too expensive to undertake after aircraft production. Training, on the other hand, can be quickly implemented. Because of the expense associated with flight instrument display changes, and the speed and cost-effectiveness of applying training solutions to the SD problem, it makes good sense to attack the SD problem through ground-based training. Except for academic instruction, very little spatial disorientation training is currently available or conducted for aircrew in the USAF today. Up until now, the most advanced ground-based SD demonstrator in the USAF inventory is a device known as the Vista Vertigon. Although the Vertigon is good for a few rotational SD demonstrations, it lacks the active feedback loop, control, motion base and sophisticated visual graphics needed to demonstrate the fallibility of human senses in the flight environment and to create the sensory conflicts common to the flight environment.

The Advanced Spatial Disorientation Demonstrator (ASDD) is a device designed to improve ground-based SD training within the USAF. With its large out-the-window visual display, its programmable head-down flight instrument display, its head-up display, and its four-axis freedom-of-motion capability, it can generate the forces and visual scenes needed to produce the conditions for most of the complicated SD-related flight phenomena. The USAF School of Aerospace Medicine (USAFSAM/FP) accepted the ASDD in September 1994. USAFSAM/FP teamed with the Armstrong Lab (AL/CFTF), and spent the next year developing SD profiles, designing a study to determine the feasibility of ASDD training technology, and executing the study. The primary objectives of the study were: 1) evaluate the ASDD characteristics, subsystems, and components; 2) evaluate the success of the developed SD profiles in generating disorienting sensations and producing sensory conflicts; and 3) evaluate the total ASDD experience for its training potential. The results of that effort are summarized here.

2. METHODOLOGY

Forty volunteer USAF experienced pilots and pilot candidates/novices (25/15, respectively) were scheduled over the course of 24 duty days (normally two per day) to complete the ASDD protocol. Each subject session lasted a total of three hours. Each subject was provided a one-hour classroom prebrief, setting the stage for the ASDD experience. Included in the prebrief was completion of a flight experience survey and the informed consent document. The prebrief covered the general physiology of SD, capabilities of the ASDD, and explanation of the specific SD illusions to be experienced during the programmed profiles. The ASDD in-cockpit session that followed consisted of two major parts--a free-fly phase (35 minutes) in the flight simulation mode, and an SD profiles phase (35 minutes), utilizing the programmable modes of the ASDD. During the free-fly phase, in addition to maneuvering the ASDD, simulating a T-38 aircraft), subjects were asked to evaluate ASDD characteristics, subsystems and components (including the visual display, instrument panel, controls (throttle, stick, rudder), and cockpit layout) by answering 52 questions regarding characteristics of these ASDD components. The subjects responded using a one-to-five scale (unsatisfactory, poor, fair, good, excellent) and could provide free-form or candid comments. During the profiles phase (each profile lasted an average of 210 seconds), subjects rated the profiles for illusion effectiveness (Type I - unrecognized SD) and for generating visual/vestibular sensory conflicts (Type II-recognized SD), also using a one to five scale. Objective data was collected when applicable. The profiles combined visual and vestibular illusions/effects, and were called Subthreshold Movement, Dark Takeoff, Graveyard Spin, Graveyard Spiral, and Black-Hole Approach. These basic profiles were developed to demonstrate to pilot trainees enrolled in undergraduate pilot training the fallibility of their senses in flight, and thus the danger in accepting sensory inputs other than the input the flight instruments provide. Immediately following the profiles phase, the subjects completed a simulator sickness and general ASDD evaluation survey upon exiting the ASDD. Subjects were also provided 24-hour follow-up symptom checklists with self-addressed envelopes in order to determine if any lingering effects or 'vertigo flashbacks' occurred, sometimes observed after high-fidelity simulator exposure. The motion sickness

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questionnaires were based on a survey provided by Dr. Robert Kennedy of Essex Corp.

3. RESULTS

3.1 COMPONENT EVALUATION. The subjects were asked to rate components and characteristics subjectively on a one-to-five scale (1=unsatisfactory, 2=poor, 3=fair, 4=good, 5=excellent). Results are reported as percent of subjects who rated it less than fair (1 or 2) or greater than fair (4 or 5).

Visual Display. The Visual Display System of the ASDD was generally rated as 'good,' but was rated lowest of all components (**5% rated it 1 or 2, and 65% rated it 4 or 5**). The visual characteristic rated highest was the display's seamlessness (**3% rated it 1 or 2, 88% rated it 4 or 5**), and the characteristic rated lowest was the depth of scene (**1 or 2=20%, 4 or 5=70%**). Nineteen subjects expressed comments regarding the depth of scene by stating the visuals depicted were too blurry or fuzzy to provide better depth perception. A comment of blurry or fuzzy visuals was expressed throughout both sessions whenever visual displays were involved, being mentioned a total of 124 times.

Instrument Panel. The Instrument Panel overall was rated excellent (1 or 2=0%, 4 or 5=95%), with the lowest rated characteristic being the communication/navigation panels (**1 or 2=8%, 4 or 5=73%**) and the highest rated being the size of the instruments (**1 or 2=0%, 4 or 5=100%**), their accuracy (**1 or 2=0%, 4 or 5=100%**), and the Altimeter (**1 or 2=0%, 4 or 5=100%**). The most frequent comment (11) on the communication/navigation panels was that they were obsolete.

Controls. The throttle, stick, and rudders were rated on average as between good and excellent (**1 or 2=3%, 4 or 5=85%**). Common throttle comments were "lack of friction adjust," "no afterburner detent," and "speed brake switch not correctly replicated" (sliding switch versus rocker type). Common stick comments included "lag in stick response," "stick too sensitive" (contradictory), and "trim requires too much adjustment" (goes out of trim too easily). Common rudder comments included "rudder pedals not realistic," "pedals need more resistance", "too much roll-not enough yaw," and "too much rudder authority/roll" (with gear up). Common overall remarks included "no wheel brakes" and "roll is too sensitive." Also noted was the fact that continual lateral stick pressure or displacement is required to maintain a bank in the ASDD, whereas in an aircraft, the stick is neutralized after establishing a bank.

Miscellaneous. The ASDD aeromodel was rated overall "More than Satisfactory." The environmental characteristics (temperature, lighting, airflow, entry/exit, audio) were all rated excellent overall.

3.2 ILLUSION PROFILE EVALUATION

Subthreshold Motion:

Background: The purpose of this illusion is to demonstrate to pilots the inadequacy of their senses in detecting certain motions of an aircraft when the motion acceleration occurs at rates below the threshold for vestibular excitation. If not detected visually, the actual quantity of displacement (total motion) is dependent on time of distraction from the instruments and can become quite large. This phenomenon has contributed to several accidents over past years and usually characterizes the early stages of more classic SD illusions. During this profile, the gondola is positioned nose tangential, then slowly accelerated to fourteen planetary revolutions per minute (rpm) while slowly banking up to twenty eight degrees. The subject was presented with an undercast/overcast day scene (no discernible horizon) which does not change as the gondola moves. The intent was for the subject to detect no motion or change of attitude until profile termination (five minutes in duration). After stabilizing at fourteen rpm, the instruments were turned on, so the subject could see the actual attitude. The profile terminated with a suprathreshold deceleration to emphasize to the subject that they were actually moving.

Findings: The subjects were asked before start of profile to report any sense of movement. No subject reported any vestibular or proprioceptive sensation of movement. All 40 subjects acknowledged their difficulty in sensing actual movement and attitude changes when shown their actual attitude via instruments and when the actual movement was described and demonstrated via deceleration. Subjects overwhelmingly rated this profile 'excellent' in convincing them they could not sense actual motion or attitude without instruments (**1 or 2=2%, 4 or 5=98%**).

Dark Takeoff:

Background: The purpose of this profile is to demonstrate to aircrew that they can erroneously perceive the actual pitch of the aircraft due to influences of linear (longitudinal) acceleration and a visual illusion. The effect of misperceiving linear acceleration/deceleration with pitch up/pitch down changes (somatogravic illusion) has been responsible for many cases of SD. This profile allows a pilot-in-the-loop (active) response requiring the aircrew to 'make the instruments read right' (level flight). The profile began with a static night runway scene (instruments not depicted), while the nose-in gondola was initially slowly accelerated in the planetary axis. Once 'cleared for takeoff,' the gondola was quickly accelerated to 14 rpm while the visuals depicted acceleration down the runway. The visual scene then depicted a takeoff rotation to 12° nose up pitch, while the gondola was 'bumped' slightly nose up (5°) with a wash back to level. The 12° pitch up caused the night runway scene to disappear completely under the nose, depicting a takeoff into complete darkness. After stabilizing at this condition, the subject was provided control in the pitch axis, and told to establish and maintain a level condition based on their seat-of-the-pants perception. After the subject's percept was stabilized, the instruments were turned on, showing actual attitude. The subject was then directed to recover to level flight as indicated by the attitude indicator. As the subject made the attitude indicator show level flight, they again perceived a strong pitch-up attitude. The subject had to overcome this seat-of-the-pants pitch-up sensation and rely on the instruments to maintain level. This active demonstration showed the subject that their senses can cause a false reality to be perceived when not cross-checking instruments, and that even referring to flight instruments may not dispel an illusion.

Findings: All but one of twenty-two subjects who were queried reported a sense of linear acceleration until takeoff rotation, at which time all subjects reported a perception of pitch-up (actual pitch-up initially 5°, washed back to 0°). Most subjects reported that the perceived pitch became extreme (>+45°), even continuing beyond vertical into inverted flight or a loop. Thirty degrees of the pitch up

sensation was accounted for by radial acceleration (converted to longitudinal acceleration by being nose in) resulting from planetary rotation. Any remaining illusory sensation was caused by the visual termination effect at pitch rotation. Upon gaining control in the pitch axis, and being directed to assume level flight based upon their sense of level, all but one of the forty subjects pushed the nose down (**$\bar{x}$=-19.0° ±7.7sd**). Upon displaying the instruments, **37 of 40** subjects reported experiencing a conflict between their perceptual level and their instrument readings. The three who did not experience a conflict established the least nose down attitude (**+4°, -3°, -5°**). The profile was highly rated (**1 or 2=2%, 4 or 5=95%**) for its ability to make subjects feel a false pitch attitude and in demonstrating a conflict between the vestibular and visual sensory systems (**1 or 2=2%, 4 or 5=95%**).

Graveyard Spin:

Background: The purpose of this profile is to demonstrate to aircrew that they cannot correctly sense the yaw (rotation) of the aircraft without an instrument (e.g., compass card, turn needle) or out-the-window visual scene. This classic illusion demonstrates an erroneous sense of aircraft yaw (opposite to actual), and then allows the subject to interpret actual aircraft yaw via instrument readings. It also demonstrates that instruments alone will not dispel the vestibular illusion--the false perception of rotation persists even when the instruments are present. However, presenting an out-the-window scene depicting actual movement does overcome the vestibular perception, thus demonstrating the value of a good visual scene for maintaining spatial orientation. During this profile, the gondola was rotated (yawed) counter-clockwise for 70 seconds up to a constant rate of 10 rpm, then decelerated to 5 rpm, while continuing to rotate counter-clockwise. No visuals or instruments were presented until the subject felt rotation contrary to actual at deceleration. After the subject confirmed the instrument readings, but still sensed contrary rotation (vestibular/visual sensory conflict present), the out-the-window visual scene (overcast/undercast cloud scene--no sky or ground) was turned on.

Findings: On an average, most subjects no longer felt rotation after 20 seconds of constant counter-clockwise rotation. Within seconds of deceleration, all subjects reported the sense of clockwise rotation (yaw). When presented with the instruments at this point, **39 of 40** subjects reported a conflict between vestibular sensations and visual instrument interpretations. Three subjects incorrectly interpreted the instruments which indicated they were rotating in the perceived direction (clockwise). It is important to note that heretofore, instruments were not designed, evaluated, or tested during an environment of sensory conflict, when a reliable interpretation is most needed. We now have that capability. Two of the subjects understood their error, and then felt the conflict. The one subject not reporting a conflict did not correctly perceive actual rotation via the instruments until the outside visual scene was depicted, at which time visual dominance disallowed any conflict from developing. This profile was very highly rated (**1 or 2=0%, 4 or 5=100%**) in its ability to induce a perception of rotation contrary to actual, and in demonstrating a sensory conflict (**1 or 2=0%, 4 or 5=95%**).

Graveyard Spiral:

Background: The purpose of this profile is to demonstrate to aircrew that they cannot correctly sense the roll and bank of an aircraft in a sustained suprathreshold turn when they rely on their seat-of-the-pants sensation. The profile began with a stable night scene (no instruments available) depicting level flight toward a small lighted town. During this visually stable period, the nose-tangential gondola was slowly accelerated using planetary rotation. A simulated radio command from Air Traffic Control to change heading preceded an increase in planetary rotation and visual roll into a turn (away from the town, into darkness), providing a right-turn visual and vestibular cue. As the visual turn progressed away from the lights, the visuals disappeared, while the planetary motion stabilized at 15 rpm with the gondola in a 30° right bank. This resulted in a gravitoinertial vector aligned with the gondola's vertical axis. To further confuse the subject's perceived orientation, a false roll-left sensation was induced via a 6° pitch-up movement (deliberate Coriolis input). At that point, the subject should theoretically perceive a bank less than the actual right bank, and if they desired to maintain the original perceived right bank, would increase right bank, producing a greater right-banked descending spiral (graveyard spiral). Instead of acting on their perception, the subjects were requested to report their perceived bank, because of the uncoordinated, unrealistic sensations that would result from tilting in either direction away from 30° when planetary rotation was 15 rpm. We feel this maneuver is at the heart of many SD mishaps where the aircrew allowed the aircraft to fly into the ground during a sustained turn.

Findings: After stabilizing in the actual 30° right bank and 15 rpm planetary rotation, the subjects were asked what bank they felt they were in. We expected the subjects to report a level percept, but instead we had extremely varied responses, ranging from a left 135° bank (inverted) to a right 110° bank (inverted) (**$\bar{x}$=-10° (left) ± 45°**), though the median and mode was 0° as expected. Because the objective was to demonstrate aircrew inability to correctly perceive the roll and bank of an aircraft in a sustained turn without instrument reference, this profile was highly successful. Additionally, though already established in a right bank, **33 of 40** subjects said they would move the controls right to maintain a 30° banked right turn, which would indeed have placed them in an unperceived descending spiral (**roll right=33, nothing=3, roll left=4**). Interestingly, the rationale of the three subjects (all experienced pilots) responding with "I would do nothing" was that they recognized they had no idea what their bank was, and were unwilling to change it for fear of worsening their situation. After asking the subjects to report perceived bank, the instruments were displayed, showing actual attitude. At this point, **37 of 40** subjects felt a conflict between their perceptual level and the instrument readings. The subjects rated this profile as excellent (**1 or 2=2%, 4 or 5=95%**) in convincing them they couldn't correctly perceive actual roll and bank in a sustained turn without instrument reference, and excellent (**1 or 2=7%, 4 or 5=88%**) in demonstrating a sensory conflict.

Black Hole Approach:

Background: This profile is designed to demonstrate to aircrew the difficulties associated with night landings caused by a lack of normal visual cues and/or visual illusions which cause them to misjudge altitude and distance. This profile allowed the aircrew to actively experience the 'duck-under' approach, with not only visual feedback but a printed depiction of their flown approach. The profile consisted of four approaches--the first three were passive demonstrations for the subject, with the last approach actively flown by the subject. The initial starting condition for all approaches was a 6.5 nautical mile

Table 1

Miles from Runway	0.65	1.1	1.55	2	2.45	2.9	
Mean Subject Altitude (ft)	129	226	334	481	636	797	
Desired 3° Glide Path Altitude (ft)	210	347	497	635	773	900	**Average**
Difference (ft)	-81	-121	-163	-154	-137	-103	**-127**

(nm) final approach, slightly off course and correcting, on a 3° glide path. The first approach was daytime, with visuals and instruments on. The approach was paused at decision height (250 feet above Mean Sea Level-MSL), and the subject was told they must report when they are at this same position/altitude on the next two approaches. The next approach was at night and the same approach was flown, but the instruments were not turned on. The subject was directed to report when they perceived they were at decision height. The next approach was identical, except the runway width was changed from 300 feet to 150 feet, and the background terrain (city lights) was up-sloped 4°, depicting a city on a hill above the runway/airfield. These alterations should theoretically make the subject feel steeper on the approach, and they would have to get closer and lower to the runway to feel at the same point as the previous approach conditions. The subject was again asked to report decision height. The last actively flown approach was the same, except the runway was also up-sloped (tilted) 2°, such that the nearer end was lower than the farther end. The runway slope was designed to further confound their ability to fly a desired 3° glide path, making them feel very steep. In addition to the above visual illusions, a false horizon (~5°) was present due to a lit street nonparallel to the horizon, which would tend to cause the subject to drift away from centerline (distracter).

Findings: On the first normal night approach (runway width 300 feet, 0° background terrain slope, 0° runway tilt, 3° glidepath), the subjects called decision height significantly higher than 250 feet MSL (**$\bar{x}$=465' ± 161'**). This demonstrated the difficulty in judging height/distance at night with little or no visual cues. On the next approach to the narrow runway/elevated background (runway width 150 feet, 4° background terrain slope, 0° runway tilt, 3° glidepath), the subjects called decision height significantly lower, and slightly below actual decision height (**$\bar{x}$=235' ± 75'**). Interestingly, the predicted effect of halving the runway width should be the perception of being at decision height at half the altitude, which was attained (465' vs 235' feet, 5' off predicted). Once paused at their decision height call, the runway width and background slope were returned to normal so subjects could compare the two scenes on the fly and note the perceptual difference. The final actively flown approach resulted in the average performance as depicted in Table1, which indicates that a "duck-under" approach occurred (runway width 150 feet, 4° background terrain slope, 2° runway tilt, 3° glidepath initially). **Fourteen of 40** subjects would have, or did, crash before crossing the runway threshold on this approach. The subjects rated this profile highly (**1 or 2=2%, 4 or 5=98%**) in demonstrating to them the difficulty associated with night landings caused by a lack of normal visual cues and/or visual illusions.

3.3 MOTION SICKNESS. The subjects completed motion sickness questionnaires (based on a survey provided by Dr. Robert Kennedy of Essex Corp.) immediately after finishing the ASDD profiles session, as well as 24 hours later. The average reported level of physical discomfort was none-to-little (**$\bar{x}$=1.8 ± .7** on a five point scale). Comments included: blurry visuals/eyestrain (n=6); uncomfortable seat (n=3)(back strain, suggested lumbar support); headache (n=3); general discomfort (n=3); and thermal discomfort (n=2). There were 26 symptoms listed on the Post-Session Simulator Sickness Survey, with none, slight, moderate, and severe as intensity options. Four subjects reported no symptoms, 28 subjects reported at least one 'slight' symptom, and 8 subjects reported 'moderate' symptoms. No subjects reported severe symptoms. Twenty nine of the 40 subjects (73%) returned the 24 Hour Follow-Up Symptom Checklist, which had the same symptom and intensity categories. Twenty four subjects reported no symptoms, and 5 reported at least one 'slight' symptom.

3.4 TRAINING EVALUATION. The subjects completed a fifteen question survey asking them to rate their experience on a 1-5 scale. The forty subjects overwhelmingly thought that the ASDD experience demonstrated the inadequacy of their sensory systems alone to maintain spatial orientation (**4.8 ± .4**). They rated the value of the nonvisual (motion) illusions between very, and critically beneficial (**4.6 ± .6**), and the value of the visual illusions was also rated between very, and critically beneficial (**4.4 ± .7**). The subjects rated the overall ASDD training as very beneficial (**4.2 ± .8**) in aiding them to recognize and cope with SD in flight. The subjects who had prior physiological training (32), rated the ASDD training as overwhelmingly greatly superior to prior training (**4.9 ± .3**). On an average, the subjects felt aircrew should receive SD training once every two years in the ASDD.

3.5 SUBJECT OVERALL COMMENTS. Thirty four of 40 subjects provided overall comments of their ASDD experience on the post-session survey. Examination of those comments provides a perspective not provided by the other data. Representative comments include (edited and condensed):

> Excellent at showing the affects of SD; just experiencing the symptoms in a controlled environment will place most aviators in a position of realizing they aren't perfect and that it can happen to them; a great improvement over other means of demonstrating SD; SD training should be incorporated in both UPT as well as periodic (annual) simulator rides throughout career; I derived the biggest benefit from the visual illusions which I have experienced routinely in operational flying; the ASDD failed to bring out that inner conflict between my eyes (learned judgment) and hands; an excellent tool for allowing aircrew members to experience SD and reinforce the reliance on aircraft instrumentation; a must for every pilot in all services; could help save lives or prevent the loss of life; SD is a feeling that can't be described in words or with pictures, it has to be demonstrated; this trainer definitely shows you how easy it is to be put into SD; a quantum leap in SD trainers–continue to pursue; should definitely be mandatory for Air Force pilots! Lets you know that there are forces out there that can really mess you up. Helps you understand that SD is not necessarily your fault, you just need to know how to recognize it; invaluable tool for UPT [Undergraduate Pilot Training]; students must be convinced that SD is a threat to staying alive; this training will be very beneficial to new aviators in explaining and demonstrating SD and it's problems. I recommend that this training be made available to all Air Force aviators, especially pilots; this training really emphasized features or points of SD that would otherwise take years to experience; lessons taught here are critical to safe flying; the illusions are very good and better than anything I have experienced in a controlled environment (instead of real aircraft); excellent training! Every pilot should experience this training; it was able to produce

situations that allowed me to become Spatially Disoriented. Then showed me why I felt this way. Making me aware of SD, thus the goal was achieved.

4. CONCLUSION

As demonstrated here, it is feasible to use ground-based motion devices with characteristics similar to the ASDD for demonstrating and training aircrew to recognize and manage spatial disorientation. The ASDD can reliably replicate a broad range of SD phenomena, providing aircrew a safe SD experience on the ground. Both Type I (unrecognized) and Type II (recognized) SD can be generated, with visual/vestibular sensory conflict present. The capability to *demonstrate* spatial disorientation using the ASDD has been developed. The capability to *conduct SD training* using the ASDD must be developed next. The training application will be limited by the amount of time (frequency and duration) aircrew or other trainees are exposed to the ASDD. However, as a demonstrator, the ASDD technology is ready for accelerated transition and operational application, while further research and development of the ASDD as a trainer continues.

AU CŒUR DE LA FORMATION SUR SIMULATEUR : LE TRANSFERT D'ENTRAÎNEMENT

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SUMMARY

Simulation used in aviation has been with us in some shape or form since the early 40's. These early devices were primarily used to teach basic flying skills and because of their simplicity had known limitations. Today's simulators are very expensive, complex and demanding devices which attempt to approximate the real world. They provide, not unlike the real aircraft, a multi-use capability where they are used for everything from teaching basic flying skills to mission rehearsals and accident investigation. These costly complicated systems sometimes provide questionable results because the designers, buyers, users and human factors specialists (which are all to often not involved) have not established a well defined set of requirements with respect to the simulators primary use. Nor do they fully understand the transfer of training from the simulator to the real world. To help understand or improve the transfer of training, human factors personnel should be involved in almost every facet of the simulators from conception to inception.

1. INTRODUCTION

Si de nos jours on n'envisage plus la formation des pilotes sans l'utilisation de simulateurs, cela est dû principalement à deux raisons : d'une part l'usage du simulateur est moins coûteux que celui de l'aéronef et, d'autre part il permet de proposer des contextes d'entraînement difficiles, voire impossible à réaliser dans le monde réel. Dans les deux cas, il est fait le postulat que les connaissances ou habiletés apprises sur l'outil de simulation faciliteront la tâche ultérieure du pilote. Ce mécanisme décrit en psychologie sous le nom de transfert d'entraînement est au cœur de la problématique de la formation et, bien entendu, de l'utilisation de la simulation. En effet, par quels moyens peut-on s'assurer que les connaissances élaborées au cours de séances de simulation constituent un apport dans la formation du pilote ? S'il est admis communément que le simulateur est un "plus" indéniable, force est de constater que dans les pratiques actuelles de formation, ce jugement résulte souvent d'une approche empirique. Face au coût croissant des simulateurs de mission, un courant se fait jour chez les utilisateurs et les responsables de formation pour tenter de rationaliser les approches liées à l'utilisation des simulateurs. Le monde scientifique est loin de posséder un savoir exhaustif et stabilisé sur le transfert d'entraînement qui permette de répondre à l'ensemble des questions posées. Ce courant n'est pas propre à l'aéronautique et touche tous les domaines militaires. L'étude qui est présentée, a été réalisée dans le cadre d'un accord européen de coopération militaire (European co-operation for the long term in defence : EUCLID) intitulé "Military Applications of Simulation and Training concepts based on Empirical Research (MASTER).

Le but de l'article est de montrer l'importance du transfert d'entraînement pour la formation sur simulateur, mais aussi la difficulté d'intégrer ce concept dans la définition des situations de formation. Dans une première partie, l'intérêt croissant pour la simulation et la définition du transfert d'entraînement sont envisagés. La seconde partie analyse le concept de transfert d'entraînement au niveau des différents intervenants de l'utilisation de la simulation dans la formation. La troisième et dernière partie vise à dégager les questions relatives à une meilleure prise en compte du transfert d'entraînement dans la formation sur simulateur pour définir les axes d'évolution indispensables.

2. SIMULATION ET TRANSFERT D'ENTRAÎNEMENT

2.1. La simulation : un outil de plus en plus utilisé pour la formation

La simulation est utilisée de façon systématique dans la formation depuis les années 40. Les premiers simulateurs ou entraîneurs avaient pour ambition d'apprendre aux futurs pilotes les rudiments du pilotage avant qu'ils ne prennent place dans un aéronef. Depuis, les simulateurs ont considérablement évolué ainsi que les

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objectifs de formation qui leur sont attribués. Le souci permanent étant d'être le plus fidèle au monde réel, on a vu apparaître des simulateurs de vol, puis des simulateurs de mission et maintenant la technologie permet d'envisager des réseaux où des simulateurs différents sont couplés entre eux. Le besoin d'une formation tactique, difficilement réalisable dans sa totalité dans le monde réel pousse les états-majors à accroître la part faite au simulateur pour la formation opérationnelle de leurs équipages. Ce besoin est accentué par trois caractéristiques : l'évolution des conditions de formation, le développement de systèmes de plus en plus complexes et la grande variabilité des missions auxquelles peuvent être confrontés les équipages.
Les contraintes et les conditions de formation évoluent en permanence. Sur le plan des contraintes, elles sont principalement d'ordre financier et tendent vers une réduction des crédits alors que le coût de formation d'un opérateur est de plus en plus élevé. Face à ces exigences, l'objectif avoué est de former dans les temps les plus courts, le plus grand nombre d'opérateurs performants. Cet objectif amène à deux remarques : d'une part l'échec a un coût et on cherche à l'éliminer et d'autre part, quel est le niveau de performance souhaité pour les opérateurs formés ? Ce dernier point est important car dans bien des cas, les critères d'évaluation d'une formation sont des critères "court terme". Il est rare que l'on prenne en compte des critères permettant de juger de l'adéquation des compétences de l'opérateur par rapport à la tâche opérationnelle finale qui lui sera demandé de réaliser. Les conditions de formation évoluent aussi dans le sens où les possibilités d'entraînement dans le monde réel diminuent en raison des nuisances provoquées (basse altitude, vol supersonique,...) et de la difficulté à construire des environnements réalistes (volume de l'espace aérien disponible, moyens à mettre en œuvre pour réaliser un cadre tactique, ...).
La complexité croissante des systèmes a plusieurs conséquences sur la formation. Tout d'abord, elle accroît les temps de formation. Les connaissances théoriques sont plus nombreuses mais surtout l'acquisition du savoir-faire nécessite une pratique beaucoup plus importante. Les travaux de Wiener (1989) sur les "glass-cockpit" dans l'aéronautique commerciale ont montré qu'après plusieurs années d'utilisation en ligne des systèmes d'aide à la gestion du vol, près de 50% de pilotes pouvaient encore être surpris par le système. Derrière ces résultats se cache un constat : la formation ne donne pas une connaissance complète du système mais apprend à l'utiliser selon une certaine philosophie d'emploi et dans un contexte nominal. On pourra toujours rétorquer que cela a toujours existé et que la formation ne peut pas dans les temps impartis garantir une connaissance exhaustive, mais ce phénomène s'accroît avec des systèmes de plus en plus complexe. La simulation prend ici toute sa place car elle devient un outil d'apprentissage et d'exploration pour un opérateur à qui l'ensemble des grandes fonctions du système a été montré. La deuxième conséquence de la complexité des systèmes est liée à l'évolution de la tâche du pilote. Pendant longtemps, les qualités qui faisaient un pilote expert étaient essentiellement des habiletés sensori-motrices centrées sur le pilotage pur. Avec les aéronefs à commande électrique et maintenant les systèmes de navigation et d'armement de dernière génération, la tâche du pilote a évolué vers la gestion des systèmes. Elle consiste à savoir bien utiliser les systèmes pour acquérir une bonne conscience de la situation et réaliser les choix désirés. Les habiletés cognitives nécessaires sont alors beaucoup plus tactiques et stratégiques et font appel à la compréhension, la prise de décision et la prise de risque sous forte contrainte temporelle. Les développer nécessite d'être confronté fréquemment à des situations réalistes difficilement envisageables dans le monde réel.
Les évolutions de la nature des missions sont un aspect opérationnel nouveau auquel sont confrontés les équipages. Pendant longtemps, les cadres tactiques envisagés étaient relativement figés et l'entraînement des équipages répondait à ce besoin. Depuis la guerre du Golfe et maintenant avec l'accroissement des missions de maintien de la paix, les équipages peuvent être confrontés du jour au lendemain à des missions pour lesquelles ils n'ont pas reçu d'entraînement spécifique. La simulation peut alors être envisagée comme un outil permettant d'optimiser l'adaptation des équipages à un contexte nouveau.

2.2. Le transfert d'entraînement

Le transfert d'entraînement ou transfert d'apprentissage est un concept qui fut introduit en psychologie au début du XXème. siècle par Thorndike (1903). Parmi les nombreuses définitions rencontrées dans la littérature, celle proposée par Patrick (1992) présente l'intérêt de s'inscrire dans une approche cognitive. Pour cet auteur, le transfert d'entraînement est l'effet produit par l'acquisition préalable d'une connaissance ou d'une habileté sur l'acquisition, la performance ou le réapprentissage d'une autre connaissance ou habileté.
Pendant longtemps sous l'influence comportementaliste (Osgood, 1949), le transfert d'entraînement n'a été envisagé que sous le seul aspect de la similarité des tâches dans un modèle stimulus-réponse. Plus il y a d'éléments identiques au niveau des stimulus et des réponses entre deux tâches, plus le transfert

d'entraînement sera important. Dans l'approche cognitive, l'intérêt se porte sur la similarité des processus cognitifs qui sont utilisés pour réaliser deux tâches et non pas seulement sur la surface apparente de ces tâches. Ainsi, l'acquisition d'un modèle mental de résolution de problème dans un contexte donné permet de résoudre un problème rencontré dans un autre contexte une fois que l'on a identifié que le modèle mental à utiliser était le même. Dans cette approche, les théories les plus récentes sur les mécanismes du transfert d'entraînement insistent sur l'importance du raisonnement analogique (Schumacher et Gentner, 1988) et l'acquisition de schémas mentaux qui puissent être transférés d'une situation à une autre (Phye, 1989).
L'ensemble de ces études permet de disposer d'un corpus de connaissances dont l'utilisation par les responsables de formation est faible. A cela, deux raisons peuvent être trouvées. La première est due à la faible implication de spécialistes facteurs humains de la formation et de l'apprentissage dans les processus de conception et d'utilisation des simulateurs. La seconde, tout aussi importante, est liée à la nature des connaissances sur le transfert d'entraînement. Les connaissances résultent dans la plupart des cas de situations expérimentales de laboratoire ou, au mieux, de situations de terrain relativement décontextualisées. Les connaissances obtenues ne sont donc pas directement transférables et nécessitent des études complémentaires pour répondre aux questions des responsables de formation. Il y a un pas à franchir entre une approche fondamentale qui décrit des modèles généraux et une approche plus appliquée qui répondrait à un besoin spécifique.

Si l'on reprend la définition de Patrick, le transfert est considéré comme un effet sur une acquisition ultérieure de connaissances. Dans le cadre de la formation, cet effet est implicitement positif dans la mesure où il doit favoriser l'acquisition et l'élaboration des nouvelles connaissances. On parle de transfert positif. Mais si la situation de formation est inadaptée, le transfert peut être négatif et devient alors contraire aux objectifs visés. Dans les apprentissages de systèmes complexes, l'ensemble des connaissances à apprendre est important et varié. S'il est facile de s'assurer que les buts principaux de la formation ne sont pas soumis à un transfert négatif, il est beaucoup plus difficile de le garantir pour toutes les connaissances. Et c'est un risque de voir se développer des transferts négatifs qui ne seront décelés que bien plus tard. Le désir de vouloir rendre les simulateurs les plus réalistes possibles, en dépit de limitations technologiques ou financières, peut aboutir à des définitions qui favorisent les transferts négatifs. Ce risque doit être connu et évalué avant tout choix de conception ou de formation.

2.3. Le transfert d'entraînement et la formation sur simulateur

La simulation est un outil de formation et, par conséquent, elle est un élément qui va favoriser ou non le transfert d'entraînement. Les questions fondamentales auxquelles sont confrontés les utilisateurs de la simulation pour garantir le transfert d'entraînement sont doubles : quelles doivent être les caractéristiques d'un simulateur qui favorisent le transfert d'entraînement et, comment doit-on intégrer l'usage de la simulation dans le cycle de formation pour avoir le meilleur transfert ? Les réponses à ces questions sont loin d'être évidentes et il n'existe pas en l'état actuel de savoir suffisamment structuré qui permette de répondre sans faille. Pour appréhender les approches qui sous-tendent la conception et l'utilisation des simulateurs, il est intéressant d'analyser les approches des différents partenaires qui interviennent dans la définition et l'usage de la simulation. Les données acquises, à travers une revue bibliographique et une étude de terrain par interviews auprès des personnels concernés, permettent de mieux cerner les différentes problématiques, les enjeux sous-jacents et les difficultés inhérentes à l'usage de la simulation pour le transfert d'entraînement. Enfin, elles permettent d'identifier des axes de travail pour une meilleure prise en compte et une rationalisation du transfert d'entraînement dans la formation sur simulateur.

3. DES VISIONS DIFFÉRENTES DU TRANSFERT D'ENTRAÎNEMENT ET DE LA SIMULATION

Différents intervenants sont ou peuvent être intégrés dans le cycle de définition et d'emploi d'une formation utilisant la simulation. Ces intervenants ont des expériences et des finalités différentes qui rendent parfois difficile une approche consensuelle. On peut identifier quatre types d'intervenants :

- les concepteurs des simulateurs, en règle générale des ingénieurs,
- les responsables de formation au sein des états-majors qui définissent les politiques de formation et y attribuent les moyens adéquats,
- les utilisateurs qui sont les personnels directement concernés par la simulation puisqu'ils sont en charge d'appliquer les programmes de formation mais ils sont aussi les premiers à pouvoir juger de leur efficacité et,
- les spécialistes facteurs humains qui peuvent aux différentes étapes intervenir pour proposer des orientations théoriques et pratiques,

aider à la définition du programme de formation ou à son évaluation.

3.1. Les concepteurs de simulateurs

Réalisateurs techniques, les concepteurs de simulateur sont des industriels en charge de construire un simulateur basé sur un cahier des charges défini par le client, c'est-à-dire le futur utilisateur. Dans une approche idéale, les choix finaux devraient résulter du travail d'une équipe intégrée comprenant à la fois le concepteur, le client et le spécialiste facteurs humains. La compétence technique est un guide sur la faisabilité des objectifs de formation. Dans la pratique, on constate que cette méthodologie est souvent biaisée pour différentes raisons : seuls les concepteurs ont une continuité dans le savoir-faire de la définition des simulateurs, les clients n'ont pas la connaissance suffisante en terme de simulation et de formation pour se positionner en véritable maître d'ouvrage, et les spécialistes facteurs humains sont rarement intégrés dès les étapes initiales de la définition. S'ils le sont, on attend d'eux plus l'énoncé de recettes "miracles" que la mise en place d'un plan d'études qui aboutirait à des recommandations adaptées.

Le concepteur se positionne le plus souvent aussi comme étant l'initiateur de la demande (désir de montrer un savoir-faire pour se positionner sur un marché). Il propose un système plus qu'il ne répond à un appel d'offre. La conséquence est que le produit présente un état de définition relativement avancé lorsque le client intervient dans la boucle de conception. La philosophie et les grands choix de conception sont alors ceux du concepteur. Une autre limite des concepteurs est de ne pas posséder une connaissance théorique "facteurs humains" minimale. Fort d'une expérience de terrain, ils ont développé un corps de savoir empirique qui révèle rapidement ses limites lorsqu'on aborde des problématiques complexes. Soucieux de cette lacune, ils cherchent de plus en plus à coopérer sur ces thèmes mais ne semblent pas encore prêt à considérer comme indispensable l'acquisition de cette connaissance à leur niveau.

Le modèle de transfert qui sous-tend la démarche des concepteurs est le modèle des éléments identiques. Plus le simulateur sera identique au système réel, plus le transfert sera important. Ce modèle guide depuis toujours la conception des simulateurs et présente l'avantage d'éluder les questions embarrassantes sur les objectifs précis de formation. En effet, "qui peut le plus, peut le moins". En proposant ce que l'on peut faire de mieux, le concepteur garantit en quelque sorte que l'utilisateur pourra faire ce qu'il voudra. Cette démarche présente cependant aujourd'hui deux limites :

- La première est celle de l'évolution des objectifs de formation. Pendant longtemps, le simulateur avait pour ambition l'acquisition d'habiletés sensori-motrices. La simulation s'est alors attachée à reconstituer des environnements physiques. Avec la complexification des tâches de pilotage, on cherche actuellement à enseigner aussi des habiletés cognitives comme la prise de décision ou la conscience de la situation.
- La seconde limite est celle du coût. Les simulateurs complets sont et seront de plus en plus coûteux. On ne dispose plus des moyens pour envisager une politique de simulation basée essentiellement sur les simulateurs les plus évolués techniquement. Il faut savoir définir avec précision les objectifs de formation aux différentes étapes de qualification professionnelle pour développer des simulateurs adaptés et en nombre suffisant.

Une autre tendance des concepteurs est de proposer des simulateurs de plus en plus attrayants, non pas vis-à-vis des problématiques de formation qui sont loin d'être maîtrisées, mais vers de futures potentialités. Cette évolution est associée à une course à la technologie avec l'introduction par exemple dans les systèmes de simulation de la réalité virtuelle (Baum, 1992) ou de la simulation couplée (Angier, Alluisi et Horowitz, 1992). Les évolutions apparaissent alors plus comme un mirage "technologique" qu'une véritable réponse aux problématiques existantes. L'impact de ces technologies est rarement évalué en terme de formation ou de rapport coût/efficacité, seules les considérations technologiques sont envisagées. D'autre part, les nouvelles technologies ne résolvent pas les questions fondamentales sur la conception et l'utilisation des simulateurs mais introduisent au contraire d'autres problématiques qui ne font que complexifier encore plus les connaissances actuelles. Si ces évolutions ouvrent de nouvelles potentialités pour la simulation, elles ne doivent pas faire oublier qu'elles doivent s'accompagner d'études spécifiques, seules garanties d'un outil de formation adapté.

3.2. Les responsables de formation

Les responsables de formation guident leurs actes par rapport à deux objectifs : l'efficacité de la formation et le coût de cette formation. Ils doivent trouver le meilleur compromis pour assurer la performance opérationnelle des équipages. Une utilisation optimale des simulateurs où la formation ne serait envisagée qu'à travers la simulation pourrait s'envisager. L'aéronautique commerciale va dans ce sens en proposant des qualifications "machines" sur simulateur avec vols de contrôle en ligne à l'issue. En aéronautique militaire, cela semble pour l'instant difficilement envisageable en

raison de la grande variabilité des missions, ce qui n'est pas le cas dans l'aéronautique commerciale, mais surtout en raison de la difficulté à simuler l'environnement opérationnel (menaces air-air et sol air, armement, systèmes de contre-mesure, météo,...). Or en l'état actuel, il apparaît que si la simulation permet de découvrir un système et les procédures pour l'utiliser, l'acquisition d'un savoir-faire opérationnel qui associe toutes les contraintes du vol est difficilement réalisable hors d'une situation de vol réel. Cela signifie que l'usage de la simulation et des vols réels sont complémentaires et qu'il faut mener une réflexion profonde sur les façons de définir cette complémentarité. Les questions propres au transfert d'entraînement apparaissent alors de façon évidente bien qu'elles soient rarement exprimées sous cette forme par les responsables de formation.

3.3. Les utilisateurs

Les utilisateurs, qu'ils soient instructeurs ou stagiaires sont au cœur de la problématique du transfert d'entraînement car ils interviennent à la fois dans la définition des simulateurs et dans son utilisation comme outil de formation.

Dans la définition du simulateur, les utilisateurs sont toujours intégrés pour s'assurer de la qualité du produit. En fait, force est de constater qu'ils interviennent plus pour valider un produit que pour véritablement participer à un processus de conception.

Au niveau de l'utilisation du simulateur et de la définition des programmes de formation, on constate une absence de continuité entre conception et utilisation. Dans un grand nombre de cas, les instructeurs se retrouvent face à un simulateur qu'on leur livre sans véritable mode d'emploi et pour lesquels ils doivent définir une philosophie d'emploi. Il apparaît qu'une démarche idéale serait d'avoir défini des objectifs de formation puis de concevoir le simulateur adéquat. On se trouve plutôt dans un cycle où on fournit un simulateur que l'on va essayer d'utiliser au mieux. Cette tâche est d'autant plus difficile pour les instructeurs que n'ayant pas de formation spécifique, ils ne disposent pas des modèles théoriques et des outils d'analyse nécessaires. Conscients de l'importance de leur tâche, ils développent des approches empiriques sans véritable évaluation.

Les principales caractéristiques de la mise en place des formations utilisant la simulation peuvent être résumées autour de trois points :

- les buts de formation ne sont pas clairs car ne faisant pas référence à la nature des connaissances à apprendre : connaissances déclaratives et théoriques, habiletés sensori-motrices liées à l'exécution de procédures et connaissances procédurales ou véritables savoir-faire cognitifs de gestion des informations. Dans la plupart des cas, les objectifs de formation correspondent à des objectifs fonctionnels qui ne présagent en rien des moyens à mettre en œuvre pour adapter au mieux l'outil de formation. Ce manque de réflexion théorique peut aboutir à une sous-utilisation des moyens de simulation qui cantonnent le simulateur a une fonction qui ne correspond pas à ses possibilités. Il en résulte de la part des instructeurs une confusion certaine entre les différents niveaux de simulation qu'offrent les simulateurs. A l'extrême, on peut se trouver confronté au paradoxe de voir des simulateurs de mission utilisés comme des entraîneurs. Il y a là un problème de fond sur l'élaboration d'une véritable politique de formation utilisant la simulation.

- la définition des cours de formation résulte souvent d'un processus empirique. La recherche auprès des instructeurs des raisons des choix de programme de formation (nombre de sessions de simulateur, thèmes abordés, place des sessions par rapport à la formation en situation réelle, ...) montre qu'il n'y a pas d'explication argumentée si ce n'est que le résultat final est globalement satisfaisant. Lorsque des difficultés apparaissent parce que les systèmes évoluent ou le recrutement varie, on adapte au mieux par des modifications les programmes existants. A l'extrême, ces évolutions peuvent être liées à des arguments matériels ou temporels. Mais il est très rare de retrouver des études comparatives entre différentes solutions qui permettent de valider les choix retenus. On peut arguer bien sûr que puisque le résultat est satisfaisant, quel est l'intérêt de développer autre chose ? En fait, il est certain que des études adaptées permettraient de mieux cerner les particularités des formations envisagées et par là-même, de proposer des cadres de formation plus performants

- l'efficacité de la formation en terme de transfert d'entraînement est rarement évaluée. Les seules données qui existent sont une appréciation d'un niveau de performance en situation réelle où l'acquis de la simulation ne représente qu'une partie de la performance globale. A travers les entretiens qui ont été conduits, il n'a jamais été fait référence à l'utilisation d'une mesure quelconque du transfert d'entraînement, qu'elle soit quantitative ou qualitative. En fait, cet état reflète le faible niveau de connaissances théoriques des instructeurs qui abordent ces questions de manière intuitive et ne peuvent en conséquence proposer une approche rationnelle.

3.4. Les spécialistes "facteurs humains"

Les spécialistes "facteurs humains" de la formation sont ceux qui possèdent la plus grande réflexion théorique sur le transfert d'entraînement

et les questions qui s'y rapportent. La littérature contient un grand nombre d'études à orientation théorique ou appliquée sur les modèles de transfert, les facteurs qui le facilitent ainsi que les méthodes et techniques d'évaluation. Il est donc surprenant de constater qu'un savoir existe et qu'il est rarement intégré dans le processus de définition d'une situation de simulation. Les raisons de cet état sont peut-être liées à la nature des connaissances établies. En effet, si l'on regarde de près les études qui existent, on s'aperçoit qu'elles sont très diversifiées et très analytiques. Il est difficile de déduire des modèles généraux directement applicables à d'autres situations de formation. Par ailleurs, la faiblesse de certains modèles ne permet pas de répondre aux questions posées et on en arrive à un paradoxe où la recherche semble soulever plus de questions qu'elle n'apporte de réponses. On peut alors comprendre la perplexité des concepteurs et utilisateurs qui dans une finalité pratique ne trouve pas ce qu'ils attendent dans les réponses de la communauté scientifique. Cela ne signifie pas qu'il faille rejeter en bloc l'approche fondamentale mais il y a sûrement un compromis à trouver entre études fondamentales et études appliquées pour faciliter une meilleure communication entre concepteurs, utilisateurs et experts "facteurs humains".

Une autre limitation au développement des études sur le transfert d'entraînement est probablement représentée par les méthodes de mesure du transfert d'entraînement. De nombreux protocoles expérimentaux (comparaison groupe expérimental - groupe témoin, transfert différentiel , approche holistique, etc....) ou de techniques de mesure (pourcentage de transfert, pourcentage de gain, ratio de gain, mesure de performance) sont décrites dans la littérature (Doireau et al, 1995). Ces mesures sont fiables mais souvent difficilement applicables par une impossibilité d'accés à des situations réelles de travail. La raison du coût est souvent avancée pour justifier ce manque de données mais il faut aussi prendre en compte la difficulté de réaliser des environnements réels réalistes. Enfin, il existe le risque pour les responsables de formation de "sacrifier" des stagiaires pour une expérimentation, dans la mesure où les protocoles proposés ne permettraient pas d'atteindre le niveau de performance suffisant, ce qui nécessiterait un cycle de rattrapage.
Une autre limitation des méthodes de mesure est due au fait que l'ensemble des méthodes proposées est centré principalement sur une approche quantitative du transfert. Les mesures prennent en compte des indices objectifs de performance et de réussite, voire des indices de temps ou de coût. On peut regretter qu'un courant de recherches n'essaie pas de proposer des approches plus qualitatives sur la nature des connaissances acquises et transférées. On sait que la performance ne permet en aucune façon de préjuger du comment de la réussisse ou de l'échec. De nombreux travaux (Spérandio, 1984 ; Grau et Amalberti, 1990) ont montré qu'à niveau de performance égal, il pouvait exister des façons de faire différentes. Cette dimension n'est pas du tout prise en compte dans une mesure quantitative du transfert. Cet engouement qui existe pour les mesures quantitatives s'explique par le souci de mesures objectives. Une approche qualitative est beaucoup plus subjective et nécessite de développer des outils méthodologiques adaptés (Guckenberger, Uliano et Lane, 1993). Force est de constater cependant que ces approches sont encore au stade du développement et justifient des travaux complémentaires pour en faire des outils d'utilisation courante.

Les travaux sur le transfert d'entraînement portent dans de nombreux cas sur l'étude des facteurs de transfert. La littérature décrit trois grandes catégories de facteurs : les facteurs liés aux caractéristiques des simulateurs, les facteurs liés aux principes d'utilisation des simulateurs et les facteurs liés aux caractéristiques des stagiaires.

Le problème fondamental de la conception d'un simulateur est la question de sa fidélité. Classiquement, on distingue deux types de fidélité (Hays, 1980) : la fidélité physique et la fidélité fonctionnelle. Sous cette dichotomie, on retrouve le débat théorique sur la nature des éléments identiques qui favorisent le transfert entre deux situations, débat évoqué précédemment dans la section 1.2. La fidélité physique relate le degré avec lequel un simulateur "ressemble" à l'équipement réel. La fidélité fonctionnelle est au contraire le degré avec lequel un simulateur "agit comme" un équipement réel. Chaque type de fidélité va avoir des implications en termes de formation et des connaissances acquises, sur la conception des simulateurs. Dans le cas de la fidélité physique, on va favoriser l'apprentissage et le transfert de savoirs procéduraux et d'habiletés immédiatement utilisables, alors qu'avec la fidélité fonctionnelle, on favorise l'apprentissage et le transfert d'une capacité à comprendre, raisonner ou prendre des décisions. L'implication directe de cet état est que la fidélité fonctionnelle peut être éloignée du réel puisque l'analogie repose sur des processus cognitifs et non sur des réalités technologiques. L'idéal pour un simulateur est bien sûr de conjuguer au mieux fidélités physique et fonctionnelle. En fait, les choses ne sont pas aussi simples car atteindre cet objectif a d'une part un coût mais d'autre part, fidélité physique et fidélité fonctionnelle ne sont pas toujours aussi faciles que cela à réaliser

techniquement. La solution est alors de savoir adapter le niveau de fidélité nécessaire aux objectifs de formation souhaités, et de connaître les limitations des simulateurs ainsi construits.
La notion de fidélité peut être abordée à travers celle de "cue" (Billman, 1987). Ce terme est utilisé en simulation pour désigner des stimulus significatifs, appris et qui caractérisent une tâche, une situation ou un contexte. L'intérêt du "cue" est qu'il va être associé à un comportement et donc à une performance. Reproduire la fidélité d'un équipement réel consistera alors à identifier les "cues" de la situation réelle pour tenter de les reproduire en simulation, voire de les renforcer pour favoriser l'apprentissage et le transfert. Pendant longtemps, la notion de "cue" a été assimilée à celle des stimuli physiques qu'ils soient visuels, auditifs ou kinesthésiques. Avec le développement de l'ergonomie et de la psychologie cognitive, l'accent s'est porté sur la notion de "cue" cognitive pour rendre compte de l'analogie entre des processus cognitifs similaires utilisés dans des situations différentes. La difficulté de la manipulation des "cues" réside principalement dans leur identification. Si certains appareillages comme la détection du regard ou l'analyse physique de certains stimulii permettent d'identifier les "cues" physiques, l'identification des "cues" cognitifs est beaucoup plus délicate au regard des outils d'analyse dont on dispose actuellement. Des progrès considérables restent à faire dans cette voie.

Les facteurs liés aux programmes de formation sont au cœur de la problématique du transfert et de la conception des simulateurs. Les travaux sur la formation décrivent de nombreux types de programme de formation. Il n'existe pas, à l'heure actuelle, de consensus sur une démarche de formation reconnue comme étant la plus performante. Les études sont nombreuses mais trop disparates dans les champs et les problématiques étudiés pour pouvoir dégager une cohérence globale. En effet, suivant les situations étudiées, tel programme de formation sera meilleur qu'un autre alors que dans une autre situation l'inverse sera vrai. Il est cependant important de noter que le choix d'une formation peut avoir des conséquences directes sur la conception des simulateurs. Par exemple, la problématique tâche complète - tâche partagée conditionnera, suivant les choix retenus, la nécessité de simulateur complet ou au contraire de simulateur limité à une partie des systèmes ou à un système seul. De même, une formation basée sur un renforcement des "retours d'action" nécessitera d'élaborer un simulateur spécifique. On voit là combien la notion de simulation peut être diversifiée avec le corollaire qu'à chaque fois, les besoins de simulation seront différents. La problématique de la simulation dans les programmes de formation laisse entrevoir la multiplicité des travaux qui restent à faire pour constituer un corps de connaissances permettant d'optimiser le transfert d'entraînement.

Les derniers facteurs de transfert sont représentés par les caractéristiques des stagiaires. De nombreux facteurs interviennent comme le niveau d'expérience ou les capacités individuelles mais on se centrera sur ceux qui peuvent avoir des conséquences pour la conception des simulateurs. Deux facteurs sont intéressants à analyser, d'autant plus qu'ils vont avoir des conséquences similaires sur la conception des simulateurs : la motivation et le stress. La motivation se définit ici comme l'implication du stagiaire dans la réussite de la tâche qui lui est proposée. Le stress est quant à lui une réaction d'adaptation à des situations pour lesquelles un sujet ne dispose pas de réponse immédiatement disponible. Dans les deux cas, la notion de réalisme est sous-jacente. Plus le réalisme sera grand, plus le stress et la motivation pourront être induits. Le désir d'accroître le réalisme amène cependant à faire certaines remarques. Tout d'abord, le réalisme aussi poussé soit-il n'est jamais la réalité, et les résultats de formation et de transfert que l'on obtiendra devront toujours être modulés par rapport à ce que sera le comportement du stagiaire dans un environnement réel. Ensuite, vouloir à tout prix le réalisme le plus grand peut conduire à créer des situations dans lesquelles on favorise un transfert négatif dans la mesure où les choix retenus pour obtenir ce réalisme ne sont pas réalisables techniquement ou le sont, mais à un coût tel que d'autres solutions techniques plus simples mais non fidèles sont arrêtées. Enfin, bien que la motivation et le stress soient considérés comme des facteurs importants pour l'apprentissage et le transfert d'entraînement, il faut avouer qu'il existe peu d'études sur ce thème et qu'on ne sait pas évaluer leurs effets réels, ce qui peut limiter les efforts consentis pour accroître le réalisme.

Cette revue des principales questions théoriques sur le transfert d'entraînement permet de mesurer l'ampleur et la difficulté que soulève cette problématique. Bien sûr, l'état de la connaissance scientifique ne permet pas de proposer un cadre exhaustif pour expliquer et prédire les mécanismes de transfert, mais il a l'avantage de faire prendre conscience des questions à se poser pour aborder la conception et l'utilisation des simulateurs.

4. QUELLES ÉVOLUTIONS DANS LE FUTUR ?

Utiliser la simulation comme outil de formation sans considérer le transfert d'entraînement est difficilement concevable. Il existe actuellement de nombreuses questions qui méritent d'être

posées si l'on envisage de spécifier un simulateur et de l'utiliser dans un programme de formation. Ces questions sont en règle générale et dans la pratique actuelle abordées de façon intuitive par les différents partenaires. Il est certain qu'une approche plus rationnelle apporterait un cadre de réflexion méthodologique qui garantirait l'élaboration d'un produit plus adapté aux buts désirés. Si l'on souhaite avoir une prise en compte plus systématique du transfert d'entraînement, il convient de mener dès maintenant auprès des différents intervenants des actions de sensibilisation pour instaurer une politique d'études sur les questions essentielles. Ces questions peuvent être résumées selon les points suivants.

4.1. Proposer un cycle de conception où le simulateur n'est pas la finalité de la formation mais un outil pour atteindre un objectif de formation. La conséquence directe est une identification claire des buts de formation qui passe par une analyse précise de la tâche et de l'activité des opérateurs en situation réelle pour identifier et spécifier les connaissances et habiletés à enseigner et transférer. Cette mise à plat est essentielle pour ensuite faire les choix de simulation les mieux adaptés. Il faut savoir choisir le bon niveau de simulation en fonction des objectifs de formation. Cette boucle de conception ne peut être qu'itérative, dans la mesure où les acquis théoriques ne permettent pas de proposer d'emblée des solutions définitives. Il convient de proposer des étapes d'évaluation des choix proposés pour les ajuster et aboutir à la solution la plus performante. Un tel cycle de conception est long et nécessite une coopération étroite entre concepteurs, utilisateurs et spécialistes "facteurs humains" de la formation.

4.2. Une conséquence directe de l'identification du bon niveau de simulation suivant les objectifs de formation est que l'usage de la simulation dans l'apprentissage des tâches complexes comme le pilotage ne peut se concevoir à travers un seul type de simulateur. Il faut développer une véritable philosophie d'usage de la simulation qui intègre aux différentes étapes de la formation des simulateurs plus ou moins complets (entraîneur, démonstrateur, simulateur de mission et simulation couplée). Associée à des considérations économiques, cette approche présente l'avantage de rationaliser les coûts de conception et de fonctionnement des simulateurs. On peut envisager la mise en place de simulateurs plus légers et plus pratiques d'emploi aux différents niveaux des échelons opérationnels plutôt qu'un seul simulateur de mission qui demande un support considérable. La formation ne se limite pas à la définition d'un simulateur qui serait le simulateur le plus complet que l'on puisse réaliser, mais bien à une véritable stratégie de formation qui intègre toutes les contraintes opérationnelles, logistiques et économiques.

4.3. La préparation des équipages aux missions qu'ils seront amenés à réaliser est un problème difficile à envisager en terme de formation sur simulateur. En effet, les cadres tactiques évoluent en permanence de même que les concepts d'emploi et les conditions opérationnelles. Si les habiletés de base comme les procédures resteront stables, il est certain que les connaissances de plus haut niveau comme les tactiques et les stratégies nécessiteront des adaptations, voire des changements importants lors de la confrontation à un nouveau contexte. On peut alors se demander comment doit-on préparer au mieux les équipages ? Doit-on leur apprendre un savoir-faire très dépendant du contexte et donc nécessitant un réalisme élevé, ou doit-on leur donner les "connaissances pour faire" en sachant qu'ils devront s'adapter à la réalité ? Parmi les "connaissances pour faire", il y a la capacité d'apprendre à apprendre (Harlow, 1949) qui est une méta-connaissance permettant de faire face aux situations nouvelles et d'élaborer rapidement les connaissances adéquates.
Cette question de fond est loin d'être réglée et a des répercussions importantes en terme de conception des simulateurs. Pour "apprendre à apprendre", la capacité d'abstraction des situations de simulation est la clé de l'apprentissage. Actuellement, il n'existe pas de données fondamentales pour pouvoir trancher en faveur d'une solution ou d'une autre. Pendant de nombreuses années, l'apprentissage de capacités générales était considéré comme la meilleure façon de faire face à la diversité des situations possibles. Mais avec un certain recul, ce n'est pas aussi évident et dans bien des cas, on préfère apprendre aux équipages une "bibliothèque" de cas pour qu'ils disposent déjà d'une solution toute prête. Le problème est l'exhaustivité des cas à apprendre, mais aussi la capacité à savoir identifier la situation et à disposer rapidement en mémoire de la solution adéquate. il apparaît ainsi que l'expertise n'est pas seulement une accumulation quantitative de cas, mais c'est aussi un traitement qualitatif qui permet de faire les bons choix. A vrai dire, il est probable comme bien souvent, que la solution réside dans un compromis de ces deux approches, ce qui a des conséquences évidentes sur la formation et l'utilisation de la simulation.

4.4. Le dernier point est la nécessité de valider les programmes de formation en évaluant le transfert d'entraînement. Trop souvent, cette phase ultime n'est pas faite et seul un retour

global sur l'efficacité de la formation est disponible. Une approche plus analytique est nécessaire pour introduire des ajustements. Face à la difficulté d'évaluer des situations réelles, il faut mettre en place un système de retour d'informations qui ne se limite pas aux résultats d'une fin de formation (par exemple examen final) mais qui intègre l'ensemble de la carrière opérationnelle d'un opérateur. Car, les données pertinentes sont celles que l'on va recueillir sur les habiletés et le comportement d'un individu dans la réalisation quotidienne de son activité et dans sa capacité de réaction aux situations nouvelles. C'est à cette seule condition que l'on pourra juger effectivement du transfert d'entraînement et des moyens utilisés pour le favoriser.

5. CONCLUSION

L'évolution des méthodes de formation se fait pour de nombreuses raisons vers un usage de plus en plus marqué de la simulation. Mais la simulation n'est pas une fin en soi et elle doit répondre à des objectifs très précis tels que la nature des connaissances enseignées et la capacité à les utiliser dans la situation réelle. La notion de transfert d'entraînement qui permet de définir l'ensemble des mécanismes associés à l'effet d'une connaissance sur l'apprentissage d'une autre connaissance est au cœur de cette problématique. Le concept de transfert d'entraînement est abordé de façon intuitive par les interlocuteurs classiques qui participent à la conception et à l'utilisation des simulateurs. Les spécialistes "facteurs humains" de la formation disposent d'un corpus de connaissances qui, bien qu'incomplet, permet cependant d'avoir une idée précise des questions qu'il faut se poser et surtout des écueils à éviter. Le corollaire de ce savoir incomplet est que la définition de chaque situation de formation ne peut se faire sur des recettes "miracle" mais doit faire l'objet d'une étude spécifique conduite par un groupe de travail associant concepteurs, utilisateurs et spécialistes "facteurs humains".

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1 - RESUME

Les performances que doit avoir un visuel de casque pour satisfaire les besoins des simulateurs de vol à basse altitude et des simulateurs multimissions sont analysées. La conception du visuel de casque grand champ SIMEYE 90™ permettant de satisfaire ces besoins est passée en revue et les compromis techniques sont explicités. Les résultats de l'utilisation du visuel de casque sur un simulateur d'hélicoptère sont ensuite présentés. Ils font apparaître des performances supérieures à la projection sur écran à l'exception du poids qui est jugé gênant par les pilotes qui ne sont pas habitués au port des jumelles de vision nocturne.

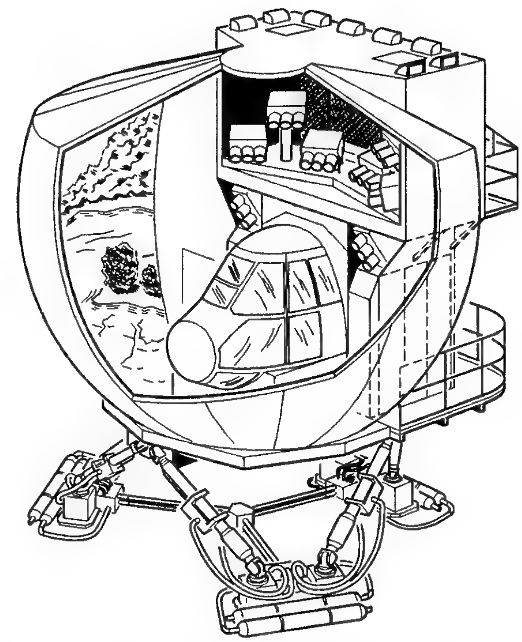

Fig. 1 - Système de projection de l'hélicoptère AS332

2 - INTRODUCTION

La restitution fidèle de l'environnement visuel est un élément primordial dans les simulateurs d'entraînement au pilotage des avions d'armes et des hélicoptères. Le besoin d'un champ visuel de plus en plus important pour entraîner le pilote à des tâches de pilotage de plus en plus exigeantes telles que le vol à basse altitude a conduit à développer des systèmes de projection multicanaux sur écrans sphériques.

A titre d'exemple, le système de projection de l'hélicoptère AS332 [1] nécessite 8 projecteurs pour couvrir un champ visuel de 200 degrés en horizontal par 100 degrés en vertical avec une résolution de 3 minutes d'arc (voir figure 1).

Les systèmes de projection multicanaux sont extrêmement coûteux en puissance de calcul d'image et ils nécessitent un bâtiment spécial pour loger l'écran sphérique de 8 à 10 m de diamètre. Les systèmes à zone d'intérêt dans lesquels l'image n'est projetée que dans la direction d'observation ont permis de réduire les coûts en puissance de calcul sans supprimer les contraintes au niveau du bâtiment. D'autre part cette réduction des coûts est obtenue au prix d'une plus grande complexité du système de projection de l'image qui doit être asservi à la direction de la tête ou du regard.

Un des moyens évident de s'affranchir de l'asservissement de l'image projetée à la direction de la tête est d'installer le dispositif de présentation d'image directement sur la tête du pilote, c'est le **visuel de casque**, qui est par ailleurs très compact et se contente d'un bâtiment standard.

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3 - ANALYSE DES BESOINS

Pour satisfaire les besoins des simulateurs de vol à basse altitude et des simulateurs multimissions, un champ visuel supérieur à 80° monoculaire, ce qui correspond à un champ binoculaire de 80° V x 120° H avec 40° de recouvrement, est nécessaire. Le champ visuel indiqué est un champ visuel instantané, le champ visuel total étant illimité car l'image est calculée pour la direction de l'observation.

Un champ visuel supérieur à 80° monoculaire est obligatoire lorsqu'il est nécessaire que le pilote soit immergé dans l'image ce qui est le cas des simulateurs d'entraînement au vol à basse altitude. En effet, si le champ est inférieur à 80°, il est possible pour les deux yeux de voir simultanément les bords gauche et droit du champ visuel [2]. Chacun des bords est vu en stéréo par les deux yeux qui les situent à une distance différente de l'image collimatée. L'image semble vue à travers une fenêtre, le pilote ayant l'impression d'être en dehors de cette fenêtre et de ne pas être immergé dans l'environnement.

La résolution de l'image nécessaire est de 3 minutes d'arc. Pour les simulateurs multimissions, il faut abaisser la résolution à moins de 2 minutes d'arc. En tenant compte de la résolution variable de l'oeil entre le centre et les bords de son champ visuel, on peut réduire la zone haute résolution à une zone couvrant un champ visuel d'environ 30°. En dehors de cette zone, une résolution de 5 minutes d'arc est suffisante. La luminosité doit être supérieure à 20 cd/m^2 et une image couleur est nécessaire.

La vision stéréoscopique est un des avantages du visuel de casque qui est particulièrement utile lorsqu'une bonne appréciation des distances proches est nécessaire comme par exemple pour le ravitaillement en vol.

Les contraintes ergonomiques sont à prendre en compte avec le plus grand soin car c'est de cette prise en compte que dépend principalement l'acceptation par les pilotes du visuel de casque. En particulier, le casque doit avoir un poids inférieur à 3 kg, un centre de gravité le plus proche possible du centre de gravité de la tête et un encombrement compatible avec les mouvements de la tête.

Les aberrations optiques doivent être les plus réduites possibles et identiques pour chaque oeil dans la zone de recouvrement des champs visuels oeil droit/oeil gauche afin de limiter les disparités binoculaires. La pupille d'observation doit avoir environ 15 mm de diamètre et le visuel de casque doit permettre la vision directe à travers le collimateur avec un rendement de transmission supérieur à 10 % pour assurer une bonne vision des instruments de la planche de bord.

La vision directe à travers le collimateur est la caractéristique fondamentale qui différencie les visuels de casque de la réalité virtuelle. En effet, dans la réalité virtuelle on cherche à recréer d'une façon entièrement artificielle l'environnement sensoriel de l'opérateur (vision, ouïe, toucher, etc.) en particulier, l'opérateur ne voit pas sa propre main mais une main artificielle entièrement calculée. Dans les simulateurs au contraire, l'environnement immédiat du pilote, c'est-à-dire la cabine de pilotage est une copie de la réalité afin d'obtenir un réalisme suffisant au niveau de la vision des instruments et des efforts sur les commandes.

Par contre, l'environnement extérieur à la cabine est comme pour la réalité virtuelle entièrement artificiel, en particulier l'image du paysage présentée par le visuel de casque vient s'incruster dans les fenêtres de la cabine.

Enfin une détection rapide et précise de la position de la tête avec une réduction et une compensation des retards de la génération synthétique d'image est particulièrement importante car tout retard de l'image, avancement saccadé ou dépassement, est immédiatement détecté par l'observateur qui devient rapidement désorienté et nauséeux. Pour obtenir une image stable et en phase avec la position de la tête, il est essentiel de calculer une image complète à 50/60 Hz et de compenser les retards du détecteur de position tête et de la génération d'image par la détection des mouvements rapides de la tête à l'aide de gyromètres fixés sur le casque.

4 - PRESENTATION DU VISUEL DE CASQUE

Le visuel de casque présenté (SIMEYE 90™) comprend un dispositif de collimation de l'image (collimateur) situé devant les yeux de l'observateur, une source d'image située de chaque côté du casque, une électronique de commande déportée, et un détecteur de position tête fixé sur le casque afin que l'image présentée corresponde à la direction d'observation (voir figure 2).

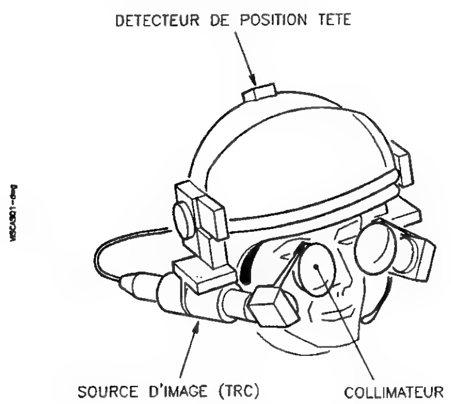

Fig. 2 - Visuel de casque

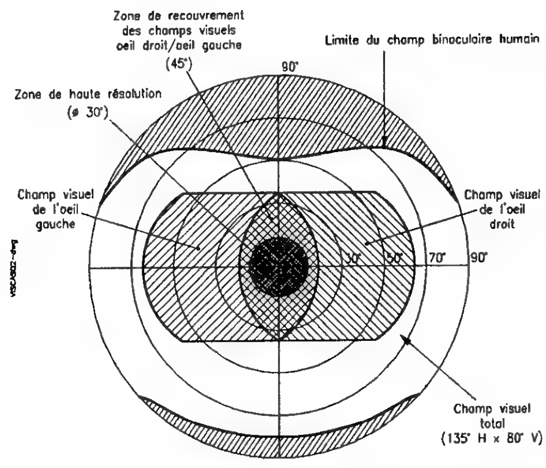

Fig. 3 - Champ visuel du SIMEYE 90™

4.1 - COLLIMATEUR

Un champ monoculaire de 90° horizontal par 80° vertical a été retenu. Ce champ est le champ maximum compatible avec les contraintes de réglages interpupillaires, de taille de pupille et de compatibilité avec le port de lunette. Par ailleurs, ce champ reste compatible avec une résolution de 3 minutes d'arc par pixel.

Le champ monoculaire de 90° permet également d'obtenir un champ binoculaire de 135° horizontal par 80° vertical tout en ayant une zone de recouvrement des champs importante, égale à 45°, ce qui accroît le confort visuel. Le collimateur peut recevoir en option une zone à haute résolution dont le champ maximum est de 30° (voir figure 3).

L'obtention d'un champ monoculaire de 90° ne peut être réalisée que par l'utilisation d'un collimateur travaillant en lumière polarisée. La technologie retenue est celle du collimateur à cristaux liquides cholestériques [3] qui offre le meilleur rendement lumineux tout en conservant les caractéristiques de couleur et de qualité d'image requises.

Le collimateur est associé à une optique relais qui inclut un prisme mélangeur lorsque l'option de zone à haute résolution est retenue. Afin d'obtenir le niveau de résolution requis sur la totalité du champ visuel tout en évitant d'utiliser une combinaison optique comportant un grand nombre d'éléments ce qui augmenterait la masse, le collimateur est constitué d'un miroir semi-transparent parabolique et l'optique relais comprend plusieurs éléments asphériques (voir figure 4). D'autre part pour réduire encore les masses, plusieurs éléments optiques sont réalisés en matière plastique, en particulier les éléments asphériques et le prisme mélangeur de l'option de zone à haute résolution. Par ailleurs, le premier miroir est réalisé sur un matériau composite nid d'abeille/carbone et la majorité des pièces de structure et les supports des éléments optiques sont réalisés en composite fibre de carbone afin d'obtenir une très grande rigidité pour un poids minimum.

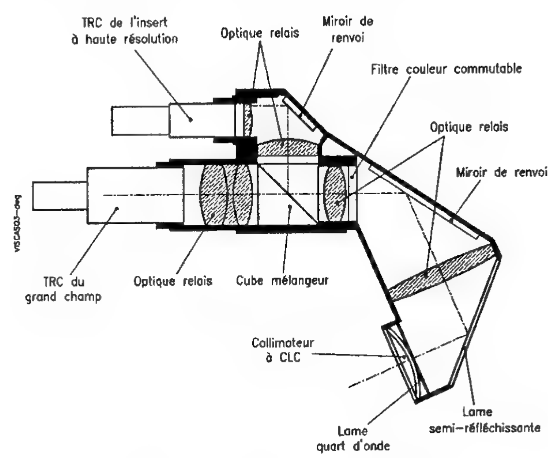

Fig. 4 - Configuration optique

4.2 - SOURCE D'IMAGE

Pour exploiter pleinement les performances d'un collimateur à très grand champ, il faut disposer d'une source d'image à haute résolution. L'utilisation d'une source d'image déportée avec transport d'image par faisceau de fibres optiques n'a pas été retenue bien qu'elle permette de disposer d'un flux lumineux élevé. En effet, les faisceaux de fibres optiques limitent la liberté de mouvement de la tête du pilote. D'autre part, les faisceaux de fibres optiques sont des composants fragiles dont les fibres cassées se traduisent par des points noirs ou d'une couleur différente des points voisins ce qui s'avère être perturbant pour le pilote.

L'utilisation d'une source d'image sur le casque a donc été retenue. Parmi les technologies actuellement disponibles, seul le tube à rayons cathodiques (TRC) permet d'obtenir la résolution de 1 800 points x 1 600 lignes requise par le collimateur à très grand champ. Les écrans à cristaux liquides (AMLCD) ou mieux les écrans électroluminescents (AMEL) peuvent atteindre cette résolution en monochrome mais pas encore en couleur. Néanmoins, par une adaptation optique, ces technologies pourront s'utiliser aisément sur le collimateur grand champ, dès qu'elles auront atteint la résolution et la taille de pixel requises.

Le TRC utilisé est un TRC monochrome blanc. La couleur est obtenue au moyen d'un filtre couleur commutable à cristaux liquides, le TRC fonctionnant en couleur séquentielle. Cette solution n'a pas d'incidence sur la résolution d'affichage, cependant elle multiplie par 3 la bande passante ce qui nécessite de disposer d'une électronique de commande rapide. Cette solution a été peu utilisée dans le passé car les générateurs d'images n'avaient pas la puissance requise. De nos jours, les générateurs le plus performants permettent le calcul d'une image de 1 800 points x 1 600 lignes en séquentiel de trame.

Les récents progrès réalisés au niveau des filtres couleur commutables permettent, lorsqu'ils sont associés à un TRC ayant un phosphore adéquat, de disposer d'une colorimétrie proche de celle des TRC couleur. Les améliorations apportées ont aussi permis d'atteindre une transmission supérieure à 25 % sur toute la bande spectrale.

Le TRC utilisé pour le grand champ est un TRC de 1,5" de diamètre (diamètre utile 29 mm) équipé d'une face avant à fibres optiques. Le phosphore est un phosphore blanc de type P45 renforcé dans le rouge, à grains très fins. Afin d'obtenir simultanément la résolution et la luminosité sans accroître excessivement la longueur, on a retenu un tube à col de 17 mm permettant d'élever la tension d'anode jusqu'à 16 kV.

Ce tube est associé à un déviateur électrostatique à faible inductance (20 μH). Par ailleurs, en raison de la bande passante très élevée nécessaire (200 MHz), l'amplificateur vidéo est installé directement sur le culot du TRC.

Dans l'option avec zone à haute résolution, le TRC retenu est un TRC miniature standard de 0,75" de diamètre à phosphore blanc et face avant à fibres optiques.

4.3 - ELECTRONIQUE DE COMMANDE

L'électronique de commande est conçue de façon modulaire autour d'une carte PC Pentium. Elle est prévue pour commander 2 ou 4 TRC (2 TRC pour le grand champ et 2 TRC pour la zone à haute résolution). Le passage de 2 à 4 TRC s'effectue par l'adjonction de cartes électroniques et d'une deuxième alimentation THT.

L'électronique est installée dans un coffret 19". Elle est constituée de 2 châssis, un châssis de commande et un châssis de puissance. L'ensemble est commandé par un PC portable servant de télécommande ou par un écran et un clavier relié à la carte PC Pentium.

4.4 - DETECTEUR DE POSITION DE LA TETE

Le visuel de casque est compatible avec tous les capteurs optiques ou magnétiques existants. Pour limiter les perturbations du champ magnétique, l'utilisation de pièces métalliques au niveau du casque a été réduite au minimum. La direction de la tête de l'observateur est gérée directement par le générateur d'image afin de réduire les retards.

5 - PERFORMANCES

Les performances du visuel de casque grand champ SIMEYE 90™ en cours de développement sont données ci-après :

- champ monoculaire : 90° H x 80° V,
- champ binoculaire : 135° H x 80° V avec 45° de recouvrement des champs oeil droit/oeil gauche,
- champ de la zone à haute résolution (option) : ϕ 30°,
- résolution de la zone grand champ : 3 minutes d'arc par pixel,
- résolution de la zone à haute résolution (option) : < 2 minutes d'arc par pixel,
- luminosité (ANSI) : 20 Cd/m^2,
- contraste (ANSI) : 20 : 1,
- distance de collimation : > 8 m,
- transmission en vision directe : > 15 %,
- réglage interpupillaire : 57 mm à 75 mm,
- écart centre de gravité casque/tête : < 15 mm,
- poids du visuel de casque : < 2,8 kg.

6 - DEMONSTRATION DU VISUEL DE CASQUE SUR SIMULATEUR D'HELICOPTERE

Le visuel de casque SIMEYE 90™ étant en cours de développement, la démonstration a été réalisée avec le visuel de casque SIMEYE 60™ actuellement disponible. Le SIMEYE 60™ a des performances similaires à celles du SIMEYE 90™ à l'exception de l'absence d'option zone à haute résolution et d'un champ monoculaire de 60° au lieu de 90° ce qui donne un champ binoculaire de 80° H x 50° V avec 40° de recouvrement des champs oeil droit/oeil gauche. Un détecteur de position tête électromagnétique a été fixé sur le casque.

Le simulateur d'hélicoptère utilisé est équipé d'un système de projection sur écran sphérique (R = 2,5 m) à 3 projecteurs couvrant un champ de 150 ° H x 40 ° V avec une résolution de 4 minutes d'arc. Le générateur d'image est une station de travail Silicon Graphics RE2 avec un logiciel SPACE MAGIC permettant par commutation d'alimenter les trois projecteurs ou le visuel de casque, la démonstration consistant à piloter d'abord l'hélicoptère avec le système de projection sur écran sphérique puis avec le visuel de casque.

Les remarques des pilotes ayant participé aux démonstrations font apparaître les convergences suivantes :

- l'atterrissage est plus facile avec le visuel de casque grâce à la vision du sol à travers les fenêtres basses de l'hélicoptère (champ total illimité),
- la qualité de l'image est meilleure avec le visuel de casque en raison du contraste supérieur de l'image (absence de réflexions parasites), d'une luminosité et d'une résolution plus uniformes et de l'absence de raccordement des fenêtres,
- l'image est plus agréable à regarder car elle est collimatée
- le casque est jugé lourd par les pilotes qui n'ont pas l'habitude de piloter avec des jumelles de vision nocturne (JVN). Par contre, pour les pilotes qui sont habitués aux JVN, le poids du casque est jugé normal. Il faut noter que le poids du visuel de casque est d'autant mieux accepté que son centre de gravité est proche de celui de la tête ce qui est le cas du SIMEYE 60™ et du SIMEYE 90™,
- plusieurs pilotes ont signalé pour la projection sur écran, des nausées (mal des simulateurs) qui ont disparu avec le visuel de casque.

7 - CONCLUSION

Le visuel de casque à grand champ qui a été présenté permet de couvrir les besoins des simulateurs d'entraînement au vol à basse altitude et des simulateurs multimissions, ceci pour un coût beaucoup plus faible que les systèmes de projection multicanaux sur écran sphérique.

Les démonstrations réalisées sur un simulateur d'hélicoptère ont fait apparaître une supériorité du visuel de casque par rapport à la projection sur écran en ce qui concerne la qualité d'image, le champ total illimité et le mal des simulateurs. Par contre, le poids du casque n'est jugé normal que par les pilotes habitués au port des jumelles de vision nocturne ce qui constitue le handicap le plus important du visuel de casque. La généralisation progressive de l'utilisation des jumelles de vision nocturne et des viseurs de casque plus particulièrement sur les nouveaux porteurs devrait habituer un plus grand nombre de pilotes à un casque plus lourd, et ainsi, avec les progrès technologiques permettant de réduire son poids, faciliter l'introduction du visuel de casque sur les simulateurs.

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[2] E.M. HOWLETT, "A Wide field of view High Resolution Compact Virtual-Reality Display" SID Symposium digest, May 1992

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REVIEW OF MOTION BASED PHYSIOLOGICAL TRAINING DEVICES

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Introduction

The use of motion based training devices permeates all of Aerospace Physiology training and continues to grow in sophistication. Motion based training devices present the opportunity for truly interactive training. However, for such devices to be completely effective, they must possess the qualities of low acquisition and operating cost, multiple task training capability, flexibility of use, and high fidelity; and they must be interactive. Future development of motion based training devices for physiological training should be a start-to-finish joint effort between customer/user groups, research centers of excellence and industry as a cooperating triad.

Customer/user groups must clearly define their training requirements and communicate those requirements simultaneously to both research centers of excellence and to industry. Additionally, they must continue to provide feedback during the development phase, troop trials, and after acceptance. Through use of the device, these groups can conduct valuable field research, the results of which must be shared with other customer/users, research centers of excellence, and industry. This information provides a valuable metric to measure the efficacy of existing devices and provides definition for future training device requirements. Customer/user groups (national and international) include both government and commercial organizations and might include the military, FAA, NTSB, ICAO and the commercial and private civil aviation communities.

Research centers of excellence could conduct research based on communicated training needs and provide state of the art information to customer/users and industry in the fields of Aerospace Physiology and Aviation Psychology. This information could assist with the development of future training for human factors, situational awareness, cockpit resource management, high g, emergency escape, and survival training. Research centers of excellence (again both national and international) could include the USAF School of Aerospace Medicine, Armstrong Laboratories, and numerous universities such as Embry Riddle Aeronautical University, and the Florida Institute of Technology, just to name a few.

The third element of the cooperating triad is industry. Industry must be responsive to customer/user needs and incorporate state of the art research information into the development of all future motion based training devices. Long term relationships with both customers and research centers of excellence will facilitate the goals of economically incorporating state of the art technology by building on previous technology while lowering acquisition cost. Motion based training devices must be economical, multifunctional, and flexible while delivering high fidelity to accommodate meaningful training for air crews. ETC continues to produce high

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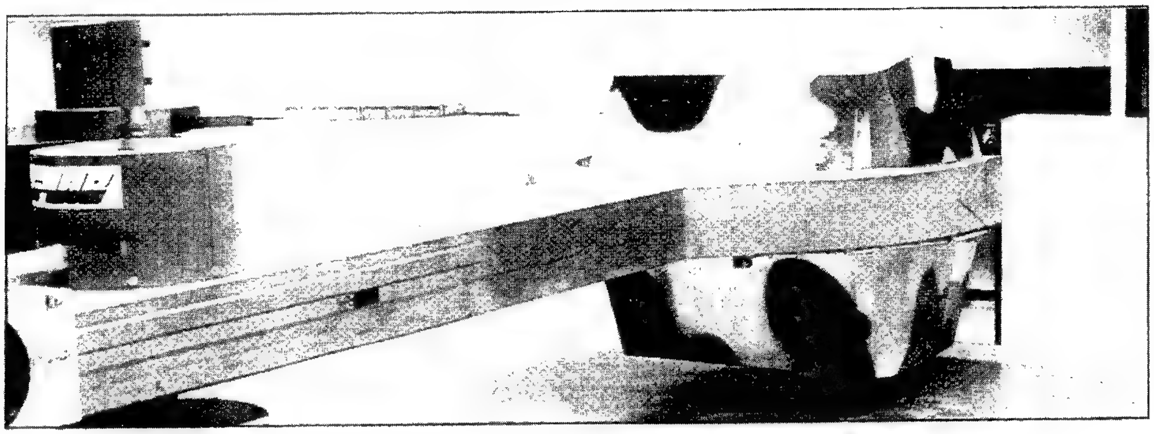
quality motion based training devices by evolving, incorporating, and building on technology as it has for over 25 years.

This paper will examine ETC's evolution of motion based training devices. Additionally, we will discuss current motion based training device applications in Aerospace Physiology training and some objectives for future motion based training devices. Last, we will describe the potential impact of new technologies on motion based device training and ETC's vision for future motion based training applications.



Evolution of Motion Based Training at ETC

ETC entered the field of Aerospace Physiology almost from the corporation's beginning in 1969 with the company's founders having been involved in the US space program going back to 1960. Their primary involvement in the design and construction of Man Rated Space Simulation Chambers provided the background for the company's first Aerospace Physiology training device, The High Altitude Rapid Decompression Flight Training Chamber. This chamber was delivered to the US Navy Corpus Christi Naval Air Station, TX in 1973. Subsequently, ETC has produced and delivered 30 additional chambers world wide to as many countries. Hypobaric chamber manufacture propelled ETC into developing and producing aviation medicine equipment and generated the financing for the original research behind the GYROLAB* and G-LAB*/ G-FET* training devices. The original ideas for these trainers came from meetings held with Dr. Allen Benson of Farnborough, UK in the mid 1970s. Dr. Benson's edited 1974 AGARD report and his subsequent book laid out the qualities of theoretically ideal training devices and this document became ETC'S road map. There have been many additional contributors along the way; notably, the late Dr. Kent Gillingham, Brooks AFB, TX as well as others too numerous to mention.

ETC'S first disorientation demonstrator, the first generation GYROLAB was sold to the UAE AF in about 1980 and is still operational today. Since that time, there have been 10 additional GYROLAB's sold, 4 of which were the 4th generation types. These devices include the ASDD at Brooks AFB and the FOT at FURSTY GAF. Another one is located in Japan at TACHIKAWA JASDF research center near Tokyo. The GYROLAB was 15 years in its evolution and still has considerable future development potential. Its four independent axes move with great precision

* Reg. U.S. Pat. & TM Off.

and are fully controlled by highly developed software which gives it the capability to accurately emulate the flight characteristics of many different aircraft . Additionally use of "glass cockpit" avionics and interchangeable templates for the instrument panel give the GYROLAB capability to precisely replicate various aircraft instrument displays.

The available 120 degree field of view, high resolution visual display and an enhanced sound system further add to this device's high fidelity. Finally, flexibility of use is further enhanced by the GYROLAB's re-configurable stick and throttle quadrant capability and it's capability to accommodate either a 13 or 30 degree seat angle.

ETC began developing and producing centrifuge training devices in the early 1980s. At that time there was considerable discussion in the USAF concerning the value of G training and the effect of varying G onset rates. ETC's first G-LAB training centrifuge was sold to the Turkish Air Force in 1985. A second G-LAB was sold to the USAF and was installed at Holloman AFB, NM. To date, this device has trained over 17,800 pilots with over a 98% in service rate. A third G-LAB was sold to the Korean AF, and a forth is installed at ETC's Aeromedical center in Southampton, PA. These centrifuges all share similar performance specifications: 6 meter arm, 15G maximum, 6 to 10 G/Sec onset/offset rates, single passive role axis with closed loop pilot control, and a computer generated target aircraft.

Several models were equipped for medical monitoring. All could accommodate either a 13 degree or 30 degree seat position (with rudders that could be appropriately repositioned). Additionally, all had closed circuit video of the pilot, and all had interchangeable center stick and side stick options.

The G-FET is a two gimbaled gondola centrifuge with active roll and pitch axes. It features an 8 meter arm, 15G maximum, 6 to 10 G/Sec onset/offset rates, closed loop pilot control, computer generated target aircraft, and an out the window 120 degree by 55 degree visual display. Additionally, it features computer generated flight instruments, interchangeable instrument panel templates and programmable flight aeromodels. The G-FET will accommodate from a 0 degree to a 90 degree seat back angle with corresponding proper rudder configuration. Several of these centrifuges were equipped with medical monitoring equipment and simulated cockpits. To date, three G-FET type centrifuges have been sold. Owners of these devices are the US Navy, RSAF Singapore, JASDF Japan.

Two years ago, ETC introduced the low cost GYRO-1, Portable Spatial Disorientation Demonstrator [PSDD]. To date, it has been produced in the Cessna 172 and the Pilatus PC-9 configurations. The GYRO-1 can currently demonstrate 10 flight illusions, but with the software tools provided, researchers and instructors can develop as many additional demonstrations as their imagination and patience will support. The GYRO-1 has the following capabilities: self-contained motion platform featuring +/- 30 degrees roll and +/- 15 degrees pitch, continuous 360 degrees of yaw, computer generated visual display, working flight instruments, accurate cockpit configuration, aircraft sound, programmable flight aeromodels, and recorded instructions for all profiles. Numerous options are available including: medical monitoring, flight training with aircraft systems, navigation training, and fault simulation; just to name few. The unusual aspect is the very low cost of this complete trainer which ranges from $120,000 to $300,000 (US).

Use of Motion Based Training Devices

Contemporary motion based training device applications for Aerospace Physiology

training include: high g, spatial disorientation (SD), situational awareness (SA), emergency egress (ground and air), and water survival training. An additional application for motion based training devices is to support human factors mishap investigation. The following discussion examines each of these applications in more detail.

High G Training:

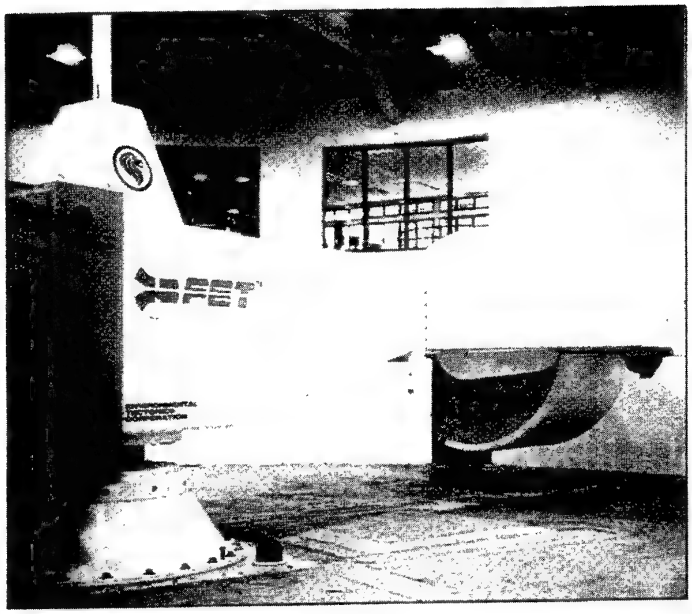
Over the past 50 years, aircraft maneuverability and thrust to weight ratios have improved at a revolutionary rate. While this has significantly improved combat capability, one unfortunate byproduct has been the evolution of aircraft that increasingly (and aggressively) challenge pilots' capabilities. This dilemma has been particularly prevalent in the area of high G tolerance and has been the object of considerable study. Academic training gave way to centrifuge training as the value of a properly executed and practiced Anti-G Straining Maneuver (AGSM) for increasing G tolerance became increasingly appreciated. (1)

The AGSM is a psychomotor activity which must be taught at the performance level and involves two objectives: actual performance of the AGSM and understanding when the maneuver must be initiated and performed. However, performing the AGSM in a one G environment can produce dangerously high blood pressures after only a few cycles.

Centrifuge training provided the air crew the opportunity to safely practice performing the AGSM, but if the rider was presented a passive role or an unrealistic scenario, understanding of when to initiate and perform the AGSM was not effectively taught. AGSM application learning requires a high fidelity, interactive device where the air crew can first practice the AGSM and then actually fly a realistic, high g mission profile. ETC first produced the G-LAB and continues to integrate new technology to support interactive, high fidelity high g training with the G-FET.

G-FET Description

The G-FET centrifuge is a man-rated, high-G rapid onset flight simulator designed to



support building G-tolerance, practicing AGSM techniques, and training in air combat maneuvers.

ETA's G-FET is a multi-axis centrifuge for high G dynamic flight training. It's wide array of training capabilities include:

- G-Tolerance improvement
- Super-maneuverability
- Unusual attitude recovery
- Situation awareness improvement
- Missile avoidance
- Air combat maneuvers
- High-G physiology research

The G-FET can produce 15G sustained acceleration at onsets up to 10 G/s. The cockpit is suspended in a dual gimbaled positioning system, providing realistic,

dynamic flight simulation.

The cockpit has closed loop flight controls, reconfigurable instruments and cockpit features (throttle, stick and rudder pedals), 0 to 90 degree seat angle capability, and wide field view, out - the - window visual scenes. These systems are integrated through advanced computer algorithms to produce high fidelity, aircraft specific performance.

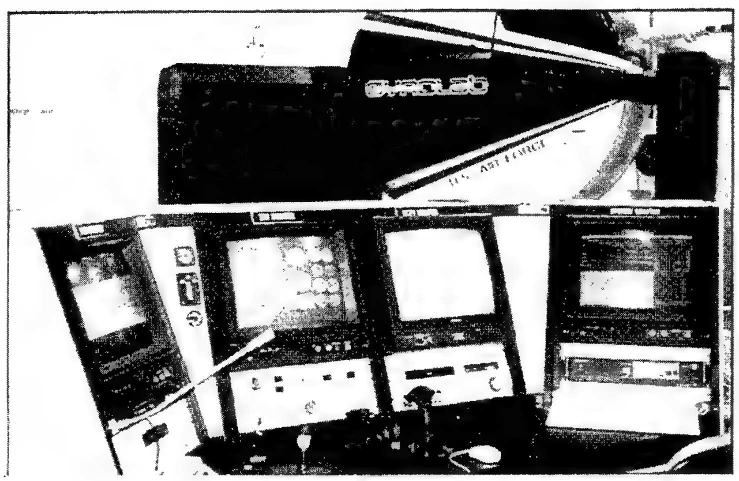
SD and SA Training:

SD and SA are two interrelated areas where the benefits of motion based training devices are readily appreciated. Sophistication of these devices has evolved from the Barany Chair (where the air crew is just a passive rider) to ETC's fully interactive Advanced Spatial Orientation Trainer, the GYROLAB. Spatial orientation is a key component of SA and when the former is lost, the latter often begins to break down. SD is categorized into three types: Recognized, Unrecognized, and Incapacitating. (2) USAF Safety Center statistics have shown that the vast majority (over 80%) of spatial disorientation have occurred because the pilot did not recognize his/her SD condition until it was too late for a successful recovery. By contrast, very few mishaps have been reported where the pilot recognized his/her disorientation in a timely manner. Accordingly, the goal of SD training is to enable the pilot to readily convert unrecognized SD into recognized SD. Pilot recognition of some illusions can be taught using the Barany chair although its capability is limited to demonstrating leans, coriollis, nystagmus and (to a degree) the effect of expectancy on resolving SD episodes. A higher level of learning occurs when the pilot not only recognizes the SD episode, but also resolves or manages it and subsequently flies through the episode, thereby developing both recognition and coping skills.

In the interactive training scenario, the pilot is required to practice recognition, resolution through use of the aircraft instruments, and task prioritization to maintain SA while performing a successful recovery. The value of interactive training was confirmed by Gillingham and Previc in their November 1993 Technical Report, "Spatial Orientation in Flight" (3) Such a high level of training is only possible in a high fidelity, multifunctional training device. ETC produces SD and SA training devices which provide a range of training capability based on customer training needs and training budget.

GYROLAB Advanced Spatial Orientation Trainer Description

The GYROLAB uses a simulated cockpit,



wide field of view virtual image display, and unique motion base technology to reproduce many of the conditions which can lead to disorientation and/or loss of situational awareness.

The GYROLAB is used for the following applications:

- Spatial orientation training
- Situational awareness management training
- Dynamic flight simulation

- Basic flight training
- Navigation and weapon system training
- Motion sickness desensitization
- Vestibular system research

The GYROLAB system features a four degrees freedom of motion base which allows up to 3 Gs sustained acceleration. The motion base supports a simulated cockpit with closed loop flight controls, operational flight instruments, and a 3D out-the-window visual scene.

The GYROLAB can simulate almost all the orientation illusions that pilots experience in flight which include:

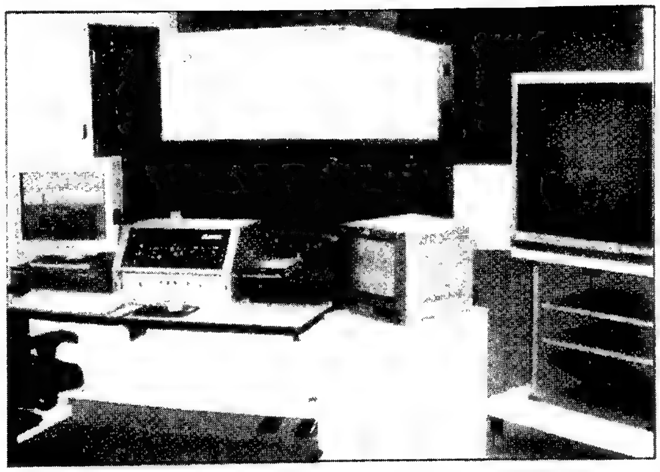
- Coriolis
- Somatogyral (Leans, Graveyard spin, Graveyard spiral, Giant hand effect)
- Oculogyral
- Somatogravic (Inversion)
- Oculogravic (Elevator)
- Nystagmus
- Visual Illusions (Approach and Landing)

GYRO-1 Portable Spatial Disorientation Demonstrator Description

The GYRO-1 is ETC's latest training device and it meets the requirement for a low cost, dynamic system that provides real-time flight simulation and can duplicate many common orientation problems experienced in flight.

The GYRO-1 was developed for low cost, portability, and reliability and is an excellent tool for the following training applications:

- Spatial orientation training
- Basic flight training
- Pilot Selection
- Weapon system training
- Motion sickness desensitization
- Vestibular research



The GYRO-1 features a reliable three degrees of freedom motion base (pitch, roll, and yaw) together with closed loop flight controls, operational flight instruments, and an out-the-window visual scene. A modular cockpit system allows simulation of light commercial aircraft, turboprop training aircraft, jet training aircraft, and helicopters.

The GYRO-1 can simulate many orientation illusions that pilots experience in flight including:

- Coriolis
- Somatogyral (Leans, Graveyard spin)
- Oculogyral
- Nystagmus
- Runway/approach illusions
- Autokinesis

Barany Chair Vestibular Illusion Demonstrator (VID) Description

The ETC V.I.D is a physiological training device designed to demonstrate Vestibular illusions due to angular accelerations predominantly in a single axis, the coriollis illusion, and to demonstrate by simulation some of the adverse effects of SD. Unlike the name infers, the "Barany Chair" is a unique and

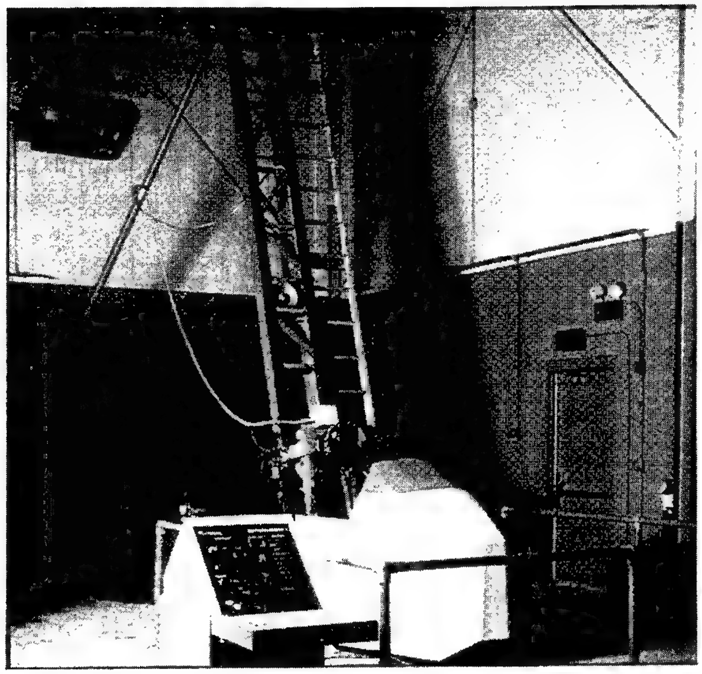
highly engineered training device innovated and perfected through stringent conformance to the military accepted codes of human engineering standards. As a flight-oriented trainer, this device is, as was its predecessor, most beneficial in demonstrating to the pilot (and also non-primary crew members) the very real effects of vertigo due to angular acceleration.

Emergency Escape Training

USAF Safety Center statistics continue to show that the number one cause of ejection fatalities is the pilot delaying ejection initiation until outside of the system survivable performance envelope. Distressingly, this problem has persisted despite significant improvements in escape system performance and capability. Classic reasons for late ejection attempts include: unfamiliarity with equipment, preoccupation with trying to salvage the situation or aircraft (misprioritization), temporal distortion, fear of subsequent reprisal, reluctance to leave the cockpit environment, and under or over confidence in the ejection system.

Aggressive training is needed to adequately address the out of the envelope ejection problem. Additionally, the goal of such training must be that the air crew sets established ejection parameters before he/she gets in the cockpit so during a serious, unrecoverable inflight emergency, the ejection decision can be made without delay. Hands-on ejection procedural training (both initial and continuation) is one important component of a complete ejection training program. The second component is realistic, interactive motion based training to support the ejection decision training arena. Often, this training is accomplished through discussion or with low fidelity training device support. A low cost, high fidelity ejection trainer, capable of presenting realistic programmed ejection scenarios could significantly enhance ejection training. ETC currently produces ejection procedural trainers and, using GYRO-1 technology, could produce the next generation ejection decision and procedures trainer.

ETC Ejection Seat Trainer Description



ETC uses state-of-the-art design in its Ejection Seat Trainer. The trainer design is based on USAF and U.S. Navy specifications, and has been modified to improve the trainee learning experience. Safety of operation is maximized by eliminating human error and allowing for adjustment of desired G-forces for each individual shot. The EST employs several unique features to assure the safe, injury free and effective training of each subject..

Our universal ejection sled incorporates adapter plates to mount the customer supplied seats. The adapter plate and seat are built as one unit for ease of exchange. The ETC Ejection Seat Trainer includes a simulated cockpit made of fiberglass.

The cockpit slides forward, for trainee entry and for exposing the ejection seat completely to better accommodate seat "test firing". This sliding feature also facilitates emergency medical access to trainee, in addition to easier seat replacement and maintenance. The cockpit instrumentation is simulated and non-functioning.

The use of a pneumatic/air system ensures proper training. It is fully adjustable and allows complete control of ejection G-force from 1G through 9G's of simulation. The desired G forces recommended for optimal training can be accurately adjusted by the instructor according to the trainee's weight to enable each subject to train under the same G force influence.

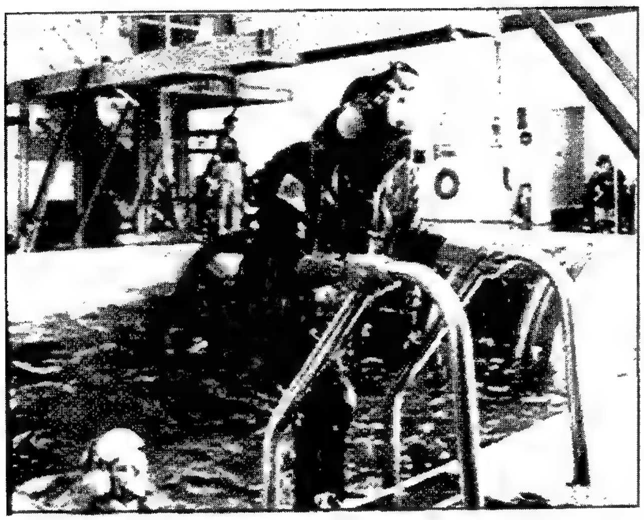
Another important safety feature is an advanced safety interlock system. The safety interlock provides for the most efficient and realistic training, while simultaneously protecting the trainee against injury. The interlock ensures that the subject is in the correct position before any seat "firing" occurs.

The instructor has complete control over the ejection seat firing and can allow the trainee to effect ejection after the trainee's review of safety precautions. The G-onset is controlled to less than 150G/second on the ejection seat trainer and is fully adjustable before training begins.

The ETC Ejection Seat Trainer is complete with all structural, electronic, compressor, pneumatic ejection pressure controls, computer control system, and necessary safety devices, which limit the rate of seat travel and monitor positioning of the trainee. The unit itself is equipped with an ejection sled that provides for the accommodation of any type ejection seat.

Potential GYRO 1 Ejection Decision Trainer

The GYRO 1 offers a low cost, interactive training option for ejection decision training. The instructor could program several ejection scenarios which the trainee could then fly. The trainee would be required to evaluate his situation and select the most appropriate course of action. Instructor critique after each scenario and subsequent trainee flying of other, similar scenarios (if the trainees performance warranted) would optimize the value of this training tool. Once again, the GYRO 1's exceptional flexibility would allow nearly as many germane, realistic , aircraft specific scenarios as the instructor's imagination would support.



Water Survival Training:

Water survival training is an integral part of an effective air crew survival training program. In this case, the training goal must be realistic, high fidelity training which is conducted in a safe, controlled environment. Training sophistication should be geared to training need so the air crew is neither over nor under trained.

Minimum activities should include ditching and aircraft escape, raft boarding, signaling, and helicopter rescue procedures. Additionally, air crews which fly parachute equipped aircraft should receive training in parachute descent, water landing procedures, getting out from under the parachute canopy, and water drags (to practice parachute canopy release). Maximum training benefit can only be achieved when the air crew is an active, hands-on participant. ETC produces a variety of water training equipment to fully support this training need.

ETC Water Training Equipment Description

Water survival training is a practical oriented discipline which requires realistic simulation of survival situations. The equipment used in survival training should be the same equipment used by the air crews day to day and training devices should be capable of simulating all aircraft types possessed and flown by the customer. ETC produces the following specially designed training devices to support safe, realistic water survival training: an Underwater Escape Survival Trainer, a Parachute Drag Trainer, a Parachute Drop Disentanglement Trainer, and a Helicopter Rescue Hoist Trainer.

Underwater Escape Survival Trainer (UEST) Description

The ETC Underwater Escape Survival Trainer (UEST) device is designed to allow air crews to practice underwater egress procedures for multi-place helicopter or transport aircraft. Underwater escape is practiced for all available exit options under both daytime and nighttime lighting conditions.

ETC's UEST is designed to be a universal trainer capable of simulating any helicopter/transport craft flown by the customer. This is accomplished by incorporating several design features which permit flexibility in configuration and operation. The major components of the UEST are the fuselage, motion system, and loading platform.

Parachute Drag Trainer (PDT) Description

The Parachute Drag Trainer (PDT) is designed to allow air crews to practice self-stabilization and parachute release skills when being dragged by a wind-blown parachute canopy after water entry. ETC's PDT is comprised of a Tower, Cable Run, and a Wall Support.

The Parachute Drop Disentanglement Trainer (PDDT) Description

The Parachute Drop Disentanglement Trainer (PDDT) device is designed to allow air crews to practice getting out from under the parachute canopy without becoming entangled in the shroud lines and parachute in the event that the parachute lands on top of them in the water. After successfully exiting from under the parachute, the trainee swims away and enters a one-man life raft which is secured by a rope to the pool edge. ETC's PDDT is comprised of a Step Platform, Drop Mechanism, and Boom Arm and Mount.

Helicopter Hoist Rescue Trainer (HRHT) Description

The Helicopter Rescue Hoist Trainer (HRHT) device is designed to allow air crews to practice the proper procedures for hoist pickup from the water during a helicopter rescue. ETC's HRHT is comprised of a Main Platform, Water Pump and Sprayers, and Hoist Mechanism.

Aircraft Mishap Investigation

A final, but very important use of motion based training devices is aircraft mishap investigation support. Through the use of a high fidelity training device which accurately models the mishap aircraft, the

mishap sequence and flight profile can be recreated. Pilot investigation board members and human factors specialists can then work together to determine where specific preventable breakdowns occurred and then develop appropriate recommendations to prevent their reoccurrence. Aerodynamics specialists could also benefit from such a device when attempting to ascertain and validate the flight dynamics of the mishap profile. This capability allows safety investigation boards to develop an accurate and complete understanding of complex mishaps and their causes and to develop recommendations to improve flight safety.

ETC provides several motion based training devices which could meet this need in a cost effective manner. The GYRO-1 portable spatial disorientation trainer, and the GYROLAB advanced spatial orientation trainer described earlier set the standard for advanced, cost effective platforms that meet this requirement. Editable flight profiles allow for the accurate reconstitution of a mishap profile for the specific type of aircraft involved.

Objectives for Future Motion Based Training Devices

Objectives for future motion based training devices include: low cost, mutiple task training capability and flexibility, high fidelity, and they must be interactive. These objectives will be discussed in greater detail.

Low Cost / Availability:

A primary consideration for future motion based physiological training devices is availability. The aviation community is a diverse, group both organizationally and geographically. A low cost training device is necessary to provide ample training opportunities to meet customer needs. Industry's challenge is to continually reduce cost while incorporating new technology. This is best accomplished by building on previous research and development while incorporating evolving technology.

A stable customer/supplier relationship is central to this strategy and is a natural offshoot of the previously described cooperating triad. Industry must be responsive to customer needs and customers must establish long term relationships with industry leaders to reduce new technology cost. Simply put, the concept of awarding to the lowest bidder may not be the most effective for future motion based training device development and acquisition since doing so often results in "reinventing the (technology) wheel".

ACQUISITION COST VERSUS OPERATING COST OF MOTION BASED SIMULATORS

	RANGE OF COST	
GYRO-1 BASIC ORIENTATION TRAINER	LOW	HI
AQUISITION COST	$150,000.00 ↔	$300,000.00
OPERATING COST/YEAR	$10,000.00	$30,000.00
GYROLAB ADVANCED ORIENTATION TRAINER		
ACQUISITION COST	$1,000,000.00 ↔	$5,000,000.00
OPERATING COST/YEAR	$100,000.00	$300,000.00
G-LAB GLOC TRAINER		
ACQUISITION COST	$3,500,000.00 ↔	$5,000,000.00
OPERATING COST/YEAR	$100,000.00	$300,000.00
G-FET ADVANCED GLOC DYNAMIC FLIGHT TRAINER		
ACQUISITION COST	$8,000,000.00 ↔	$18,000,000.00
OPERATING COST/YEAR	$300,000.00	$500,000.00

Multiple Task Training Capability / Flexibility:

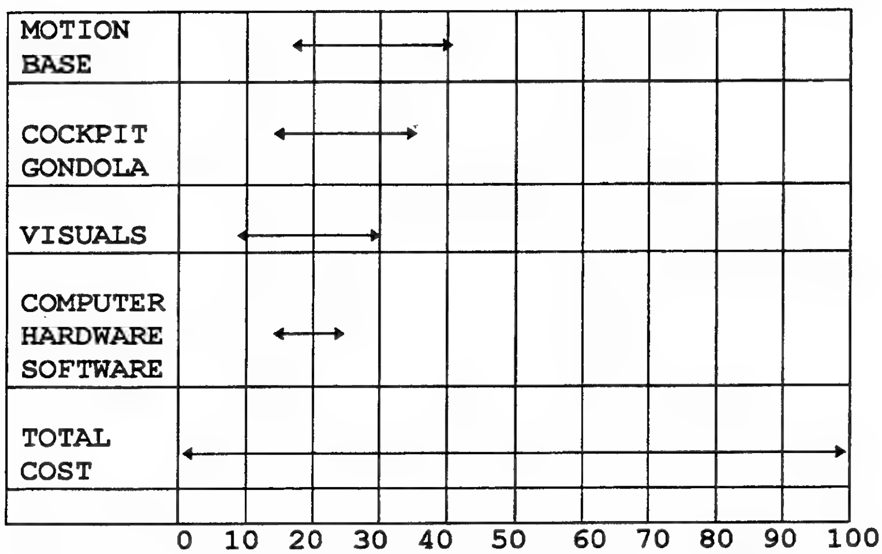
Future motion based training devices must also be exceptional values. Certainly low cost is one way to achieve this goal. However, another significant objective pursuant to this goal is multiple task training capability and flexibility. Future generation training devices must be capable of effectively supporting more than just aerospace physiology training. For example, a high G trainer could also Function as an aircraft simulator, a SD trainer, and a SA trainer. ETC's low cost GYRO-1 capabilities are being continually expanded to perform more aspects of SD training. Additional potential applications certainly exist in pilot selection screening and in support for mishap investigation. Ejection trainers need to have incorporated capability to support both air and ground egress with high fidelity. Finally, water survival training facilities may be expanded to include capability to support hydrotherapy and aerobic exercise protocols.

Fidelity:

A primary goal of any training device is to minimize negative transfer and/or student frustration during training. Accordingly, high training device fidelity is a primary consideration for both current and future training devices. Although some latitude with gross cockpit layout may be possible to allow a device to emulate several different aircraft, flight characteristics and avionics layout must accurately mimic the actual aircraft. Visual systems must present realistic, wide field of view displays to enhance training realism. Finally, motion systems must allow the training device to respond smoothly and accurately to pilot

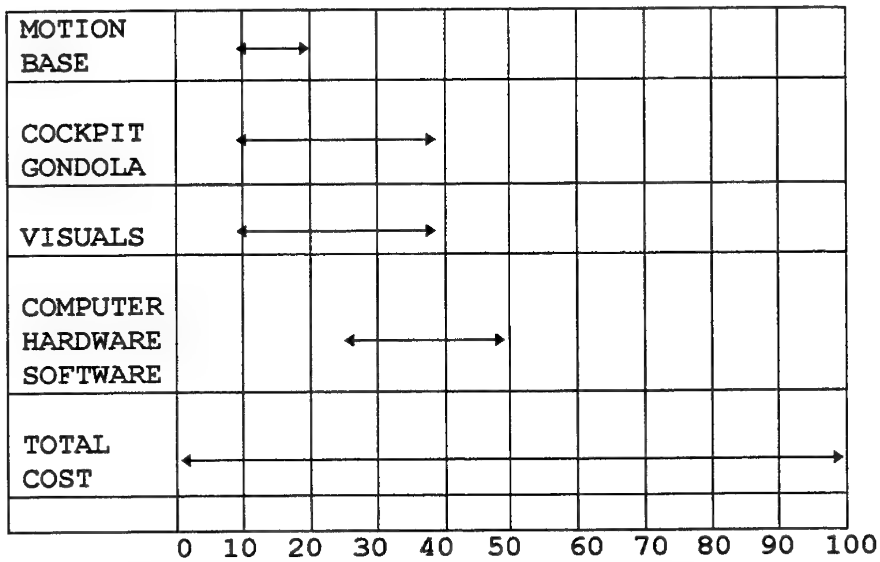
inputs. These requirements suggest the need for aggressive and continuing software development for aircraft flight characteristics programs, highly capable computer hardware support for the device and a smooth four axis motion system capable of accurately emulating the feel of the actual aircraft in flight. The high cost of this technology must be and can be brought down through long term industry-customer/user-research centers of excellence relationships. Precisely determining which qualities are necessary to achieve high training device fidelity may require additional research and may prove to be situational. The goal is to generate the highest possible fidelity at the lowest possible cost and to not allocate large sums of money for training device capabilities that only contribute minimally to fidelity. The chart shown below shows a sample cost analysis of what ETC believes are the current major contributors to high training device fidelity.

PER CENT (%) COST DISTRIBUTION FOR A DEVELOPED TRAINER



PERCENTAGE OF ACQUISITION COST OF A DEVELOPED TRAINER

PER CENT (%) COST DISTRIBUTION FOR A NEW TRAINER



PERCENTAGE OF DEVELOPMENT OR RESEARCH COSTS TO PROVIDE A NEW TRAINER OR TO IMPROVE FLIGHT FIDELITY OF EXISTING TRAINERS

Impact of New Technologies

There are several evolving technologies that will impact the continual development of motion based physiological training devices.

1. Analytical software tools will allow the modeling and subsequent improvement of virtually every aspect of the device. For example: System dynamic performance, System stress levels, Modal characteristics, Life span and fatigue aspects, System failure mode analysis.

2. The ongoing development of computer graphics hardware and software tools will allow for significant developments in the out the window visuals and the instrument displays. Scene quality will also improve with the use of downloaded satellite terrain elevation and topographical data. The cost to incorporate geological specific data will also be considerably reduced in the near future. Visual display hardware including projection systems, CRT's, flat panel displays, and optical display systems are all continually improving. These improvements will produce greater visual scene resolution, faster scene update rates, additional scene content and more scene realism with textured and shaded visuals.

3. Computer hardware and software developments will produce both significant performance improvements and also cost reductions. Increased computer processing speeds and multifunctional capabilities will allow for fewer lower cost computers to replace the complicated mainframes of today. Software language improvements will reduce the time to create software code and will also reduce the hardware-software integration time. In turn, software documentation will also improve and will allow for continuing evolution of training device capability.

4. Cockpit fidelity will improve with better understanding of what features actually drive fidelity and subsequent greater attention to the details of the specific aircraft cockpit. Cockpit layout will be enhanced through the use of increasingly available micro/miniature switches and components.

5. A challenging area that needs significant improvement is that of improving the availability of low cost, high fidelity aircraft flight performance models. Currently, these models (if available) are restricted to only very high cost flight simulators. There are two accepted methods for development of a flight aeromodel. The first (and best) is to fly the specific aircraft, instrumented for flight data collection, throughout its entire performance envelope. This is a very expensive procedure and it is limited by aircraft configuration and the allowable safe flight envelope of the aircraft. The second (and more promising) method is through computer modeling of the aircraft with some limited validation where necessary and possible. This method is currently also very expensive. If the aviation medical field is to properly address the SA challenge, we must find a way to develop low cost aircraft flight performance models.

The Future of Motion Based Training Devices

Motion based aerospace physiology training addresses a significant number of psychomotor skills. SD, SA, Acceleration, Emergency Escape and Water Survival training all have the objective of the air crew correctly responding to a situation by performing a series of learned tasks. Due to these training requirements, interactivity must be a primary consideration for all current and future training devices. The value of hands-on training when learning is targeted to the performance level cannot be overemphasized. (4) Accordingly, current and future devices need to maximize student involvement and minimize student passive roles.

Simulator training has similar, if not the same goals. Given the similarity in training methodologies, a logical progression is the melding of simulator, Aerospace Physiology, and Aviation Psychology training. This training could be economically supported with carefully designed, multiple task training capable, flexible, high fidelity training devices. The primary training goal of any organization is to maximize operating effectiveness (i.e. combat capability, passenger service, flying proficiency, etc....) while also maximizing flying safety. ETC's vision supports that goal: **To constantly improve quality and training capability while simultaneously lowering training cost by incorporating evolving technology, flexibility and high fidelity into each succeeding motion based training device through close interaction with research centers and customer/user groups.**

Summary

Motion based training has proven to be an effective way to economically and safely teach complex, psychomotor flying and survival skills. However, for motion based training devices to effectively support this kind of training, they must possess the qualities of low acquisition and operating cost, multiple task training capability, high fidelity, and flexibility; and they must be interactive. Effectively supporting future air crew training needs would be facilitated by a cooperating triad consisting of customer/user groups, research centers of excellence, and industry. ETC has been an industry leader in the development and fielding of high quality, state of the art motion based training devices for over 25 years. We are dedicated to improving quality and capability while lowering acquisition and operating cost on each successive training device through the integration of evolving technology.

This paper has discussed the evolution of motion based training devices at ETC and current uses of motion based training devices. Objectives for future devices was described as was the impact of new technologies for motion based training devices. The paper concluded with a vision for the future of motion based training devices where Aerospace Physiology, Aviation Psychology and simulator training would meld into one discipline and could be economically supported by well chosen, multifunctional, high fidelity training devices. This vision would be facilitated by a cooperating triad of industry, research centers of excellence, and customer/user groups.

About the Authors

William F. Mitchell is the founder, president, chairman and CEO of Environmental Tectonics Corporation (ETC). Over the past 25 years, he has established ETC as the industry leader in motion based training devices for aerospace physiology, water survival and ejection training. Additionally, he directs product lines which produce computer based training systems, Aeromedical training devices, hypobaric chambers, hyperbaric chambers, commercial sterilization equipment, and environmental test equipment. ETC also provides training and field service functions in over 30 countries world wide. Mr. Mitchell holds a Bachelor of Science degree in physics and has completed graduate work in mechanical and electrical engineering. He is a member of the ASME and Drexel University engineering advisory boards. Additionally, he is a member of ASME, SAE, ISPE, UHMS, AMA, and the Institute of Environmental Sciences. He also serves as the ASME representative on the National Laboratory Technology Transfer Committee.

Richard A. Leland is the Director of the Aeromedical Training Institute, a division of ETC. Mr. Leland has over 10 years experience in the Life Support field, over five years experience as an Aerospace Physiologist and is a former USAF instructor pilot with over 3100 flying hours in three diverse aircraft. He holds a Bachelor of Arts degree in Biology and a Master of Arts degree in Human Resources Development. Additionally, he is a certified Hyperbaric Technologist by the National Board of Diving and Hyperbaric Medical Technology.

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THE USAF ADVANCED SPATIAL DISORIENTATION DEMONSTRATOR PROGRAM

A Framework for Future Spatial Orientation Training

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32. SUMMARY

The search for ground-based devices that can generate realistic motion and forces of an aircraft in flight is ongoing. However, with the maturing of several technologies, mostly in the computer and visual arenas, the Advanced Spatial Disorientation Demonstrator (ASDD) has surfaced as the prime United States Air Force (USAF) candidate. It combines these new technologies to generate repeatable and sustainable flight-like forces with unsurpassed fidelity. The device, though still in its infancy, has proven that realistic spatial disorientation (SD) illusions can be generated in a save, ground-based environment. This program overview highlights the ASDD's capabilities, which will have a dramatic impact on the way pilots will receive SD familiarization training for the next decade.

INTRODUCTION

Ever since man took to the air in his wonderful flying machines, he has been faced with the hazards and sometimes fatal consequences of SD. Attempts to construct ground-based simulators, trainers or demonstrators of this pilot killer have met with varying levels of success. Over the past decade, the ceaseless efforts of one pioneer in the study and research of SD have resulted in the design and procurement of the latest in state-of-the-art, ground-based, SD demonstration devices. With significant guidance from Dr. Kent Gillingham, the ASDD was accepted by the USAF in late 1994.

Over the past year the energetic team of USAFSAM/FP and AL/CFTF formed a cohesive group focused on refining and exploiting a multitude of capabilities possessed by this world class device.

The design of the ASDD represents the integration of several technologies that have finally matured into a single device. These technologies include high resolution visual displays, high-speed, low-cost computer motion controls, and advanced programming languages that can orchestrate a completely synchronized flight and motion simulation. By coupling these with actually putting the man-in-the-loop, to not just observe a demonstration but to actually interact with the device and experience the sensations of disorientation, the USAF has created a unique training capability. It is with great pleasure that we present, for the first time outside the United States, a release of information concerning the USAF's most advanced tool for combating inflight SD the ASDD.

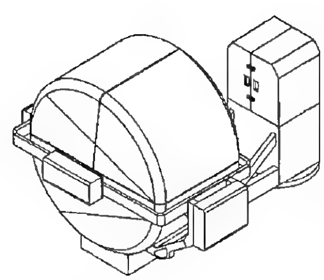

Figure 1. The ASDD

ASDD OVERVIEW

This discussion starts with a brief look at the impact SD has had on the USAF in lost aircraft and lives. It then defines SD and examines how the ASDD addresses each part of this definition. This is followed with a look at what makes the ASDD unique, the ASDD program goals and objectives, and finally, the ASDD approach to the SD problem.

Paper presented at the AMP Symposium on "Selection and Training Advances in Aviation", held in Prague, Czech Republic, in May 1996, and published in CP-588.

The Impact of SD on the USAF

Just what has driven the USAF to even consider pursuing a new ASDD device? One way to answer this question is to review the cost SD imposes on the USAF. Historically, from 1972-1994 (22 years) the percentage of mishaps attributed to the **operator**, has been as high as 69%. Of operator-related mishaps, the SD portion has been as high as 40%.

Looking even closer at what has been happening more recently, in a five year review of the Class A mishap rate (1990-1994), SD can be found as a major factor in 29 mishaps involving the loss of 31 aircraft and several fatalities. The total dollar value exceeds $374 million. Just in the last year, while we have been evaluating the ASDD, there have been four other mishaps involving SD, adding more than $100 million to this cost. The cost continues to average approximately $80 million per year. To our knowledge, there is no **new** program that is trying to directly tackle this cost.

The Definition of SD

It is important to have a common definition of SD in order to reproduce it. When developing the ASDD program, we used the following basic definition from Dr. Gillingham. (Ref 1)

"A SENSE OF ONE'S LINEAR AND ANGULAR POSITION AND MOTION RELATIVE TO THE PLANE OF THE EARTH'S SURFACE"

The Joint Situational Awareness / Spatial Orientation Technical Working Group also desired a slight expansion to this definition by adding the phrase:

"Or relative to another aircraft..." to the end of the definition.

This addition emphasizes that the erroneous sense of motion and position cannot only be relative to the earth, but also relative to another aircraft or object. This factor was the driving force behind some of our latest software modifications that incorporated formation-flying visual displays.

Another critical point to the SD problem is the basic understanding of how pilots sense their orientation. A basic "laundry list" of the senses pilots use to obtain their orientation in flight are:

Visual, Vestibular, Somatosensory, and Auditory

The important thing about how pilots utilize these senses is that they follow a prioritization. Pilots will invariably revert to their visual sense, or allow what they see to dominate their orientation. Take the visual input away by putting them in the weather, flying at night, head down in the cockpit, or turned back to check the six o'clock position, and they revert to vestibular senses to maintain their spatial orientation, and so on. It is essential that an SD training device be able to manipulate all these senses to be truly effective.

ASDD and Situational Awareness

There are those who feel that SD is not an entity to be considered separately from situational awareness (SA). They feel that even though it has significant impact on a pilot's performance, SA training is where emphasis should be placed when training pilots for today's fast-paced, high-workload flying environment.

We agree that SA is indeed important and does warrant a great deal of attention. However, pilots can lose their SA without becoming spatially disoriented and can still fly the aircraft in relative safety. HOWEVER, if pilots **do** become spatially disoriented, their SA is definitely in jeopardy, as is their safety.

Spatial Orientation is Only a Part of the Situational Awareness Bubble

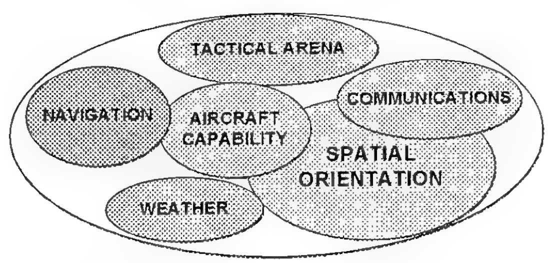

Figure 2. The SA Bubble (Ref 2)

SA incorporates numerous areas, each with its own characteristics. For illustration purposes, only a few areas are included in Figure 2. By breaking the larger problem into manageable parts, we can attack the SD portion of the SA bubble and come one step closer to solving the very large and complex issue of loss of SA.

Roadmap to Countering SD

The "roadmap" to countering SD has four basic pathways:

1) *Understanding Physiologic Mechanisms—*
This will be done through continued research, and improving the technology base. It is important to continually strive to understand the basic physiological principles involved in human senses of orientation.

2) *Improving SD Training For Our Pilots—*
This is the mission of the ASDD. Inflight SD training is expensive and inherently dangerous. Historically, this training has been comprised of unusual attitude recovery procedures or unique aircraft handling characteristics and has not normally incorporated SD illusions or sensory conflicts. Today's focus is still on quality ground-based, classroom instruction with rudimentary demonstrations in devices such as the Barany Chair or Vertigon. The ASDD is a quantum leap in this training capability.

3) *Enhancement of Flight Instrument Displays—*
This is a long-term fix, using devices such as helmet-mounted displays to aid in pilot orientation or even such unique devices as the US Navy's tactile orientation garment vest.

4) *Development of Automatic Flight Systems—*
These systems include automatic ground collision avoidance and pilot activated automatic recovery systems similar to that used in one of our advanced fighters.

There is a need to continue development of inflight SD demonstrations to enhance pilot awareness. These could successfully be integrated with ground-based curriculum and training using the ASDD to reproduce each particular illusion. This would provide pilots the time and environment to properly distinguish SD illusions from other flight sensations.

The ASDD program started under the guidance of the renowned Dr. Kent Gillingham, who was considered to be a world expert on SD. What makes the ASDD unique over any other ground-based simulator or centrifuge is that it incorporates all five of the criteria that Dr. Gillingham envisioned as **essential** for a quality SD device. (Ref. 1) They are:

1) *Enhanced Visual Displays—*
From recent "troop trial" results, (Ref 3), high quality graphics are essential. Previous research into virtual reality displays proved ineffective and drove the design of the current type visual system.

2) *Full Range of Motion—*
Smooth, full-ranged motion. Up to 360 degrees of angular rotation is highly desirable.

3) *Man-In-The-Loop—*
A critical requirement. The pilot must have an input in order to create an interactive, realistic simulation.

4) *Realistic Flight Instruments—*
The devices cockpit instrumentation has to resemble and perform as much like an aircraft as possible.

5) *Variable Task Loading—*
Task and workload are an integral part of the SD as well as the SA equation. Provisions must be available to increase the intensity of pilot workload.

ASDD Program Goals and Objectives

- Provide the most realistic, ground-based, SD training and research device possible.

  -- Provide basic, reliable training profiles

  -- Train aviators to recognize and cope with SD

  -- Research/develop advanced profiles

Our objectives, along with the device itself, have continued to evolve, with the main thrust always being on training the aviator, our primary customer.

What Makes ASDD Unique

The following is a quick outline of the motion and visual capabilities of the ASDD:

Motion System

♦ 4 angular degrees of freedom: 360 degrees in pitch, roll, yaw and planetary

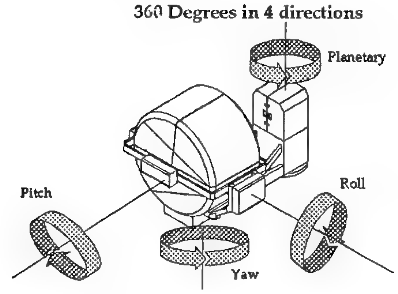

Figure 3. ASDD Motion

♦ 2.2 G's sustainable around an 8-foot planetary arm that can be rotated up to 28 RPM.

♦ Subthreshold motion. The electric motors are so smooth and quiet that the occupant does not sense the motion, which can be less than 0.5 deg/sec.

♦ Precision (+/- .01 degrees in motion or .01 seconds in time). Computer programmable profiles to the exact position necessary to produce the illusion are simplified through user friendly "profile utility" software. Simple profiles can be constructed in minutes.

♦ 150 millisecond response time. Gondola movements are nearly as quick as the actual aircraft, giving it a very realistic "feel".

♦ Man-in-the-loop or passive, computer-driven motion. Such motion is totally operator selectable, allowing the occupant to interact with the profile maximizing the experience.

Visual System

♦ 114 x 58 degrees seamless field-of-view. Utilizing a system of curved screens and mirrors, the pilot's view is not cluttered by any seams or monitor frames. This feature was rated "very high" during the troop trial. (Ref 3)

♦ Infinity optics. All images are focused to infinity.

♦ Formation flight. Both fighter and tanker images flying their own independent paths allow for increasing the pilot's workload. Pilots can record their flight and then replay it while flying in formation with themselves in real-time. The tanker has an independent programmable flight path for realistic air-refueling anchors.

♦ Computer-generated images using Silicon Graphics computers. Visual scenes are programmable in the using Silicon Graphics environment using Performer software.

♦ Cockpit (T-38 layout). Medium fidelity cockpit with actual T-38 throttle quadrant and control stick.

♦ 4 Aeromodels (T-38, F-16, F-15, A-10). Source code for each aeromodel is programmable and the site license is owned by the USAF.

♦ Computer-generated instruments and a virtual HUD are programmable, lending maximum flexibility for future modifications. Incorporation of an overlying metal bezel gives the instrument panel a realistic appearance.

♦ Independent navigation monitoring screen. The ASDD operator can monitor the flight path of not only the pilot but the independent tanker as well. Additionally, a simulated Instrument Landing System / Precision Approach Radar (ILS/PAR) monitoring screen allows for exact tracking of pilot progress on approaches. Approach trajectories are also recordable on hard copy with a connected laser printer.

♦ Flexible cockpit configuration. Two control sticks are permanently mounted in the gondola. The center stick is utilized by the T-38, F-15 and A-10 aeromodels. The side stick is utilized by the F-16 aeromodel. Neither conflicts with the other.

ASDD Approach to the SD Problem

One of the unique capabilities of the ASDD is its ability to combine variable visual illusions with vestibular sensations. Other simulators move, but they do not have the breadth of combined motion and visual flexibility possessed by the ASDD. Many current simulators have their visual scenes hard coded onto computer chips to get the visual frame rate required for simulated flight. The ASDD's visual scenes are totally software-driven and have the flexibility to be changed, even in the middle of a scenario. This allows for some dramatic visual demonstrations to pilots, such as, to demonstrate the visual impact that differently sized runways have on their perception of height above the ground on an approach. With the touch of a button, the runway width can be changed, right before their eyes. Cloud decks can be sloped, right before their eyes. These and other instantaneous changes in the visual scene allow pilots to immediately discern the impact of visual phenomena on their ability to accurately fly the aircraft by visual references alone.

The vestibular capabilities of ASDD are likewise just as variable. The operator can either manually control the gondola movement, design a computer controlled profile, or have the pilot control gondola movement directly or through the aeromodel. The device has maximum flexibility.

When designing the pilot profiles, the Human Systems Center (HSC) team went through numerous discussions as to the approach to the three types of SD. As presented below, they are simply categories of SD based on pilots' **cognitive perception** of their attitude, position, and motion.

Type I - *Unrecognized* SD. Pilots are oblivious to their disorientation, and control the aircraft completely in accord with and in response to a false orientational precept. (Insidious in nature, sometimes called *misorientation*)

Type II - *Recognized* SD. Pilots consciously perceive some manifestation of disorientation, may or may not be aware their perception is incorrect, and are taking steps to actively control the aircraft. (Pilots may not know the source of the problem).

Type III - *Incapacitating* SD. Pilots experience an overwhelming response to physical or emotional stimuli associated with the disorientation event. (Pilot is disoriented, knows it, but can't do anything about it). (Ref 1)

These definitions are very useful in categorizing mishaps but are **not** as useful when determining which profiles or scenarios that a SD demonstration device should incorporate. There is an important paradigm shift necessary for the educator to understand in discussing SD and devices such as the ASDD. What is more practical for building profiles and scenarios is isolating the individual illusions themselves. For example, the illusion of pitch-up caused by acceleration during an afterburner takeoff can be Type I (unrecognized) if pilots are not cross-checking their instruments on an instrument takeoff into the weather. This same illusion could be considered Type II (recognized) if pilots feel the pitch-up, cross-check their instruments, and fight the urge to push the nose of the aircraft over, because they know the sensation is just an illusion. The focus of the ASDD profile construction has been to create the **illusion** itself rather than the specific Type I or Type II profiles.

ASDD Additions

As with any prototype device, the ASDD did not come with all the features the initial planning team envisioned. Upgrades had to be added later as time and money allowed. Most of these items were not available during the ASDD "troop trial." Many of these modifications were driven by recommendations received from the "troop trial". Hopefully, when future ASDDs are purchased, these and other improvements will be incorporated.

Hardware

♦ Actual T-38 throttle quadrant. This added a realistic afterburner detent and realistic feel for the pilot.

♦ Separate audio system. Addition of programmable engine noise to more closely match the four different aeromodels increases simulation realism. Also, addition of user recordable voice instructions that are selectable by the console operator add a dimension not normally found in simulators. Students can receive exact instructions for each profile, or the operator can elect to personally direct the pilot's actions.

♦ Printer for hard-copy of pilot approaches. This hard-copy "proof" of the pilot's exact performance greatly enhances the credibility, and hence the value, of the demonstration received.

♦ New video projector. The "troop trial" highlighted the inadequacy of the original video projector. The installation of a state-of-the-art projector with segmented screen focusing systems improved the crispness of the seamless scene and greatly enhanced the demonstrations and realism.

Software

♦ Refined aeromodel. A major challenge in the ASDD development effort was to improve the accuracy of the aerodynamic algorithms. Detailed source code modification was required. The USAF purchased a site license from the manufacturer in order to have free reign on this redesign. The result is an aeromodel that is praised by instructor pilots as the best they have flown.

♦ Enhanced visual scenes. The Armstrong Laboratory brought in independent software programming expertise to sit down with the researchers and accurately design the visual scenes required. This greatly enhances the realism of the pilot profiles.

♦ Independent tanker / fighter. As mentioned earlier, these additional independent aircraft can interact with the pilot to increase the workload and more realistically emulate the inflight environment.

♦ Enhanced navigation screens. The console operator can accurately track and even direct the pilot to a specific position or target.

♦ Expanded approach screen. The pilots ILS approach can be accurately monitored and printed out to show deviations from planned course. This screen can be used for console operator directed PAR type approaches.

♦ Added G-meter. Addition of an accurate G-meter to the computer generated instrument suite enhanced

the pilot's ability to perform accurate aerobatic maneuvers.

Profile Development

The development team approached the profile development task by following the "keep it simple" philosophy. Five "basic" profiles were written, that demonstrate a pilot's inability to accurately perceive motion in the three axes of yaw, pitch, and roll. (Ref 4). These were coupled with a few purely visual illusions that were targeted at the new Undergraduate Pilot Training student. Prior to the "troop trial", potential acceptance of the training's value by highly experienced pilots was still an issue of concern. It was feared they might view the ASDD as a glorified "carnival ride". This was not the case, however, and the team was gratified by the very high marks the profiles received during the "troop trial".

The HSC Team plans to develop seven new and more advanced profiles by the end of this year. These will build off of the experience gained in constructing the basic profiles and will target the experienced pilot.

The HSC team has worked closely together with the other two countries owning similar devices, Germany and Japan. We have had working group meetings to share trial experiences and openly discuss pilot profile design. The synergistic effect of working together has allowed this group to collectively progress much farther that any single organization could have by itself.

How Many ASDDs Does the USAF Need?

If we limit the ASDD training to just pilots (not including fighter weapons systems officers or navigators), and planned on training the entire USAF (~12,500 person) aircrew flying pilot population, just one time each, we get the following calculation:

Conducting eight single pilot sessions a day, with 45 minutes per session, it would take 9½ **years** with just one device!

Putting 12 pilots through a day, and cutting down the time of the training session, it would take over 6 **years** to train them all. This is too long. We need more simulators to increase the time allowed for each pilot and also provide more frequent refresher training.

To answer questions concerning recurring training we can look at the data another way, asking "If we want to train all of the pilots every three years, how many devices would we need? This assumes that we can also wait three years for the initial training. If we train up to eight pilots a day for every single training day available, four ASDDs will work. However, this assumes we could funnel all of the pilots through those four locations which is not necessarily feasible. A number of six might be more practical. (Information based on a year's worth of working days minus 76 programmed maintenance days, 10 Holidays and 10 vacation days.)

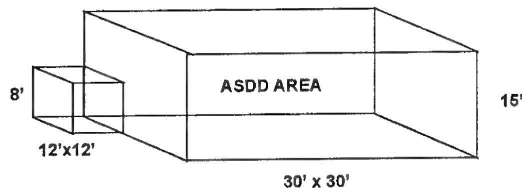

Figure 4. ASDD area

Another common question that arises is "How much room do you need to accommodate an ASDD?" Figure 4 represents a typical block of space that could minimally house this device. By providing a high-voltage power source and a suitable floor structure, installation is relatively straight forward.

Figure 5 shows a typical footprint view of what an ASDD installation might look like when installed at a typical USAF Physiological Training Unit. It requires a considerable amount of space as well as special mounting to the floor due to the lack of any counterweight for the gondola.

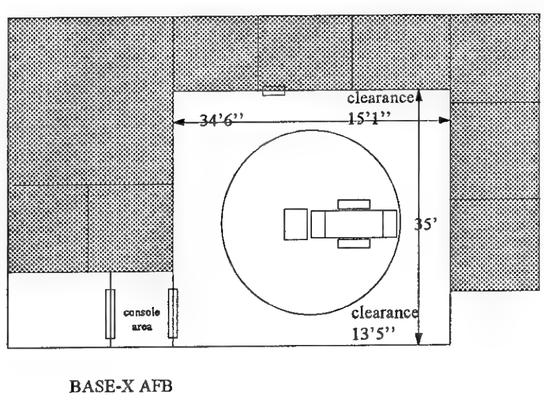

Figure 5. ASDD Typical Footprint

We have not found the lack of a counterweight to be a significant problem however. At Brooks AFB, the ASDD is mounted to the existing concrete flooring

suspended 5 feet above the earth. The flexing of the flooring is easily controlled with a simple metal substructure.

SUMMARY

The success of the ASDD program has been the direct result of a consolidated and cohesive team effort of not only the USAF Human Systems Center members but also their counterparts in the German and Japanese programs.

It is critical that the ASDD address all of the pilot's senses of balance or "spatial orientation". It does this quite well. The ASDD meets all five of the criteria set forth by Dr. Gillingham and as of yet, the ASDD team has only scratched the surface of each of these areas. The key to the ASDD's success is in its flexibility of software programming. This is where the future lies in capturing many of the advanced profiles or illusions.

It is hoped that with such tools as the ASDD we can improve the SD coping skills of our pilots and hopefully have them gain a better **respect** for the subtleties and dangers of SD. It is crucial that the flying community understand that the ASDD will be a potential life-saver when it is fully implemented with clearly definable and repeatable illusion and sensation profiles.

We need to improve our pilots' understanding and awareness of SD, for it is not easily defined and is often misunderstood. The real use of the ASDD is putting pilots into a situation where they actually experience the illusion. This way they know that if they put the airplane within certain parameters, they are setting themselves up for that illusion. Pilots can thus be prepared to cope with SD and perhaps avoid it altogether.

We envision future aviators will associate the ASDD with SD training as readily as they associate high-G centrifuges with G-LOC training. Apart from fielding ASDD as a training device, future development may even begin to tackle the SA problem in a more realistic flight simulation. The training and research over the horizon promises to be as exciting as the work that brought the ASDD to its present level of performance.

The study of SD and the attempts to train pilots to recognize as well as gain respect for the often subtle nature of this killer has a long history with a somewhat unsteady momentum. The past 70 years have seen numerous devices such as the classic Barany Chair (which is still used today), crude angular devices like the Ocker Chair, the Ruggles Orientator, the Link trainers of WW II, the Vista Vertigon, the Multistation Disorientation Demonstrator, the Vertifuge and now the ASDD. This long list of potentially life saving devices will surely not stop with the ASDD. Unfortunately, the only device that can truly simulate the forces and sensations of what a pilot actually feels in flight is an aircraft. However, with both aircraft and flying-hour costs rising while the defense budget is shrinking, the goal of designing a ground-based simulator of these sensations is a worthy one.

For as long as USAF pilots continue to take to the air, as long as they continue to fly in the face of their enemies to protect their freedom and way of life, and as long as they press the limits of their human performance to be the best in the world—it is worth all of the toil and effort to provide them the absolute best training, research, and devices our aeromedical research community can muster.

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THE FLIGHT ORIENTATION TRAINER AS A DUAL PURPOSE DEVICE: TRAINING VERSUS AEROMEDICAL RESEARCH

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Summary:

The German Air Force acquired the "Flight Orientation Trainer (FOT)" and installed it in the facilities of the German Air Force Institute of Aviation Medicine (GAF IAM) in Fürstenfeldbruck to improve its training efforts in aviation physiology and especially in spatial disorientation

In 1994 a troop trial was conducted to have the FOT tested and evaluated by experienced pilots of the German Armed Forces.

Results of the troop trial are described and the best timing for training in the FOT is discussed.

The evaluation and validation of the FOT requires calibration and counter-measure equipment to cover various aspects of spatial orientation, situation awareness and motion sickness.

The relevance of pilot´s ability to react under changing orientation can be shown in a orthostatic stress test on tilt-table. An individual susceptibility for syncopal reaction can lead to loss of awareness and motion sickness.

1. Introduction:

The German Air Force acquired the Flight Orientation Trainer (FOT) as a tool to familiarize its pilots with the hazards of spatial disorientation and to teach them ways to recover from it.

From the beginning of the acquisition it was intended to use the FOT for research purposes, but, in the first place the purpose of the FOT was advanced training of aircrews against the dangers of spatial disorientation.

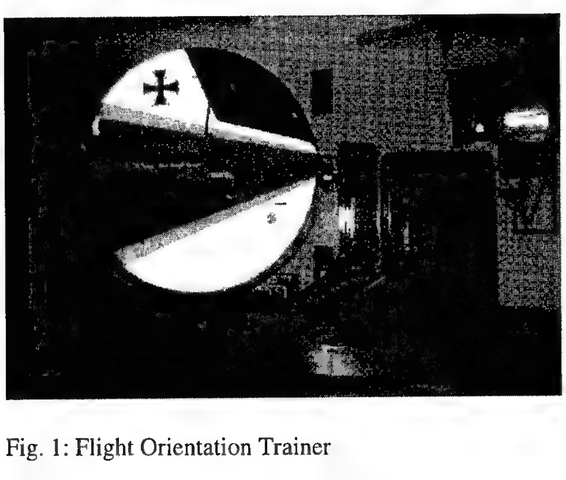

Fig. 1: Flight Orientation Trainer

2. System description:

Figure 1 and 2 show an overall and a diagrammatic view of the Flight Orientation Trainer, which consists of the gondola, the roll-frame, the yaw-frame, and the planetary arm attached to the central post. The purpose of the planetary arm is to generate forces up to 2.2 G.

The student sits in front of a concave mirror with a field of view of 120 x 40 degrees into which a computer-generated environment is displayed.

Below the mirror, a monitor shows the instruments for speed, flight altitude, flight attitude, engine performance and the nozzle position, the compass, and the vertical velocity indicator for the climb and/or descent rate (VVI).

The cockpit is equipped with the normal flight controls, stick, rudder pedals and throttle levers for engine control.

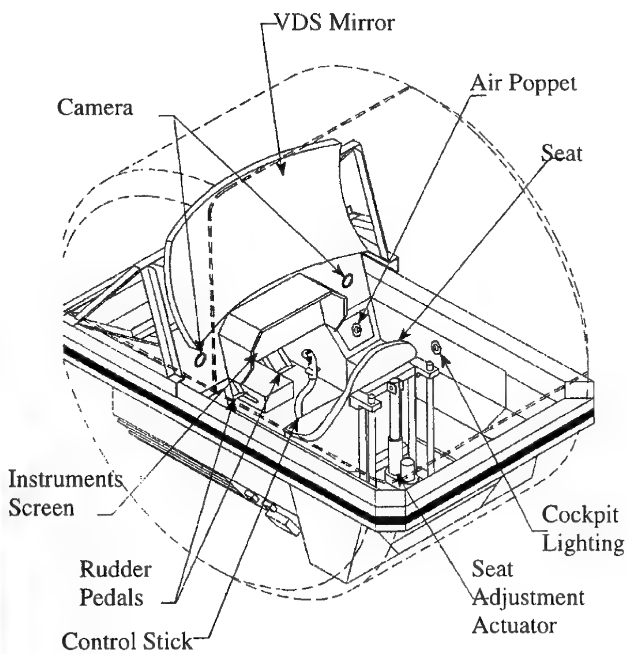

Fig. 2: Transparent view of FOT

Unlimited movement is possible about all 3 spatial axes and the so-called planetary axis.

The planetary arm can produce G forces of up to 2.2 G which may act on the pilot in any direction, depending on the speed of the rotation and the position of the gondola.

Paper presented at the AMP Symposium on "Selection and Training Advances in Aviation", held in Prague, Czech Republic, in May 1996, and published in CP-588.

A unique characteristic of the FOT, in contrast to other flight simulation systems, is the ability to move freely around all spatial axes. In particular the movements around the yaw axis increase the realism of the flight simulation.

In order to simulate realistic flight conditions, the FOT can be used like a flight simulator in a so called "flight mode".

The FOT's so-called "flight profile mode" makes it possible to record a flight with all its visual display and motion parameters for further use in training.

Depending on the training purpose, the student can either passively experience this situation or actively influence it like in a real simulator flight, once control has been transferred to him, which is possible at any moment.

The visual display and the instrument display can be modified from outside, for example by changing the daylight conditions, by "freezing" the instruments or by selectively "blacking them out". Thus, the stress for the student is increased and he is more susceptible to disorientaion.

In another mode, the so-called "ground profile mode", the patterns of movement are developed by preprogramming the movement of every axis, individually.

For each individual axis, the movements are programed accurately in advance. It is possible to preprogram the transfer of control for one or more axes individually at a specified time. This transfer of control is a fixed factor of profile programming and, in contrast to the "flight profiles", cannot be influenced from outside.

Upon transfer of control, the response characteristics of the FOT to control inputs change since the so-called "aeromodel computer" is not in the control loop in the ground profile mode.

The FOT then no longer reacts by simulating aircraft-typical movements but translates control inputs directly into gondola movements without regarding the aircraft simulating software program.

Therefore, it is sometimes problematic to hand over control to an unexperienced student in ground profile mode because he will be likely to overreact, thus getting into a situation which he cannot control and which may have severe side-effects, as e. g. motion sickness.

The computer is capable of simulating the profiles by demonstrating the movements of the FOT on the screen using a CAD program.

The linear and angular accelerations acting on the pilot and the corresponding forces are also shown on the display. Thus, program errors can be detected before the profiles are actually flown by human beings.

The content of the visual part of the profile is completely independent of the motion part of the profile, so that the two parts of the profile may contain contradictory informations for the pilot on purpose.

3. Troop Trial - Methods:

During the troop trial in the year of 1994, 29 training profiles covering a wide range of visual and vestibular illusions were tested and evaluated by a total of 22 pilots. 8 of those were jet pilots, 12 were helicopter pilots and 2 were pilots of transport aircraft.

With the help of questionnaires and debriefings the pilots were asked to evaluate hard- and software of the FOT and its flight characteristics.

The details of the evaluation have been described earlier by Pongratz et al. at AGARD 1995.

4. Conclusions of the Troop Trial:

The result of the troop trial can be summarized as follows: Mainly vestibular illusions are produced very well whereas some of the visual illusions are considerably limited, due to the insufficient performance of the visual display system, which lacks computer power to generate sufficient resolution and an image-update frequency high enough.

The pilots who conducted the test found training in the FOT desirable and useful.

They agreed that the student should be trained after a previous flight experience to be able to handle the controlforces and to understand the situation and their relevance in real flight conditions.

However, this is only necessary if the flight profiles are used and the training scenario consists of a complex inflight situation, as e.g. landing approaches.

The flight experience is not needed to demonstrate illusions for which active cooperation of the gondola passenger is not required or for which the student just has to make limited control inputs as e.g. isolated inputs in only one axis, or inputs with a very small motion amplitude.

Differences were found in the acceptance of a repeated FOT-training.

Jet pilots whose routine included IFR-missions stated that further training sessions in the current form were not necessary after completion of their fast jet training and after being permanently stationed in their units. But they regarded the training in the FOT as being valuable if it could accompany their basic flight training. The FOT training should end with the Europeanization of the pilots.

The helicopter pilots, especially those without IFR ratings, were very interested in further demonstrations of possible illusions, even if their flight experience amounted to several thousand flying hours. But they requested hard- and software modifications to match helicopter-specific handling chracteristics. This necessity was repeatedly demonstrated by the same kind of input errors conducted by different pilots: In dangerous flight situations the pilots pulled out the thrust of the engines, because this movement equals the increase of engine power and lift in a helicopter by pulling the collective pitch lever. Other obstacles are the different speed and glide path angles in helicopter operations. And at present it is not possible to simulate "hovering" in the FOT.

Another experience was the occurence of at least two severe cases of simulator sickness, which would have caused to ground both pilots for three days or more. By circumstances both pilots did not have to fly in the week after their FOT-flights, but we were - and are - very concerned about the induction of motion sickness in the FOT and of the consequences for the training of pilots both regarding flight safety and the danger of a possible negative transfer.
For the 94-troop trial this meant that we decided not to have the helicopter pilots test those profiles which made intensive use of the planetary arm in order to simulate the G-excess-effect, because we suspected this to be at least one trigger factor for the simulator sickness in the FOT.
All pilots agreed that a substantial upgrade of the VDS is necessary.

5. Aeromedical Research:

The evaluation and validation of the FOT as a research tool was and is closely connected with the problems of spatial orientation and its disturbances like loss of awareness and motion sickness.
One of our aims is to validate training success in the FOT. This requires research on the neuro- and sensory physiologic basics.
The troop trial has also proved the necessity to evaluate the possible side effects of the FOT training.
The use of the FOT as a research tool required the procurement and integration of additional equipment in the periphery or in the FOT itself. For the interpretation of the collected data, reference methods had to be selected. Static and dynamic orientation as aspects of the spatial orientation also had to be covered.

The reference methods and re-equipment of the FOT cover:
- posturography, to examine static and dynamic orientation,
- tilt table, for cardiovascular reaction after changes of the body orientation in pitch,
- videoculography, which allows to record the horizontal, the vertical and the torsional eye-movements
- polygraphy including Electroencephalography (EEG).

Static orientation is tested on a posturography platform which measures the oscillations of the body by determining the Center of Foot Pressure (CFP) after exclusion of visual influences (Romberg-Test). The vestibular system can be disturbed e.g. by rhythmic head movements, and the proprioceptive system by conducting the test with a layer of foam on the platform.
The sway and the area of the index are calculated comparing the conditions "eyes open with the fixation of a target" and "eyes closed" without fixation.
At present experiments are being conducted to evaluate the influence of several FOT-profiles on the vestibular system, i.e. how severe are the disturbances of the vestibular system and what is their duration?

Fig. 3: Posturography with test person

Figure 3 shows the platform and the test person.

A simple form of dynamic orientation resulting from the standardized stress-test (that is a pitch motion) is performed on the tilt-table. The perception of movement in space is not only vestibular but also autonomic in nature and depends on several control circuits that can be influenced in part voluntarily by respiration.

Fig. 4: Orthostatic stress test: test situation

Figure 4 shows the standardized "orthostatic stress test" conducted at the tilt table. Recorded parameters are heart rate variability, blood pressure, and respiration frequency.
Figure 5 and 6 show two different reaction patterns of the heart frequency under identical orientation conditions.

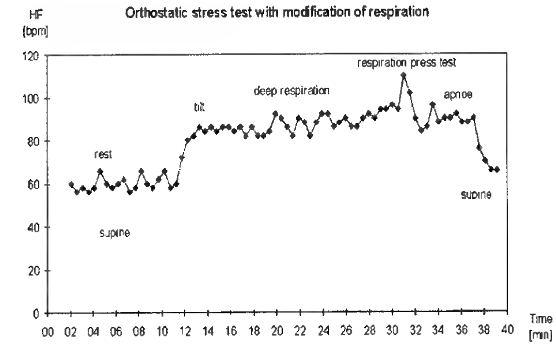

Fig. 5: HF of a UH-1-pilot (tilt table)

Figure 5 shows the reaction of a 36-year old UH-1 pilot with a destinct increase of the heart frequency, a destinct modification by respiration and a clear recovery.

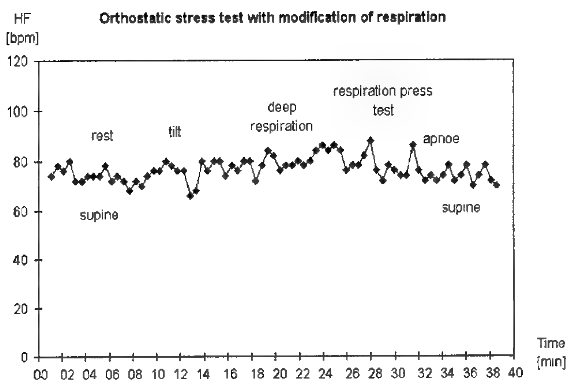

Fig. 6: HF of a UH-1 crew-member (tilt table)

In contrast to this reaction Figure6 shows the reaction of a 32-year old UH-1 crew-member: The values "in rest" are slightly increased, but the reaction on the orthostatic stress and on the respiration is less clear. The recovery is delayed.

Figure 7 shows the influence of the respiration, (6 s inspiration, 4 s exspiration) on the heart frequency as a stimulus for the autonomous nervous system).

The heart frequency is increased by inspiration and decreased by exspiration. The deep respiration is a strong stimulus which causes an arrhythmia.

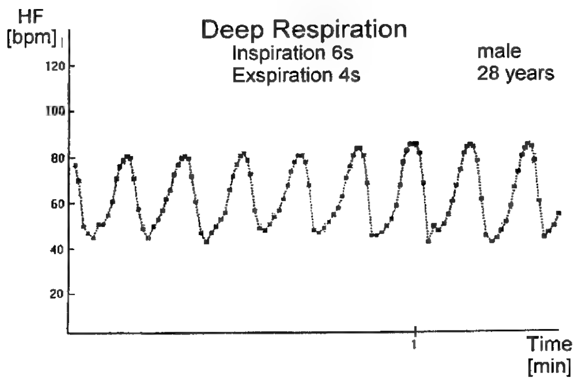

Fig. 7: Influence of respiration: "Deep Respiration"

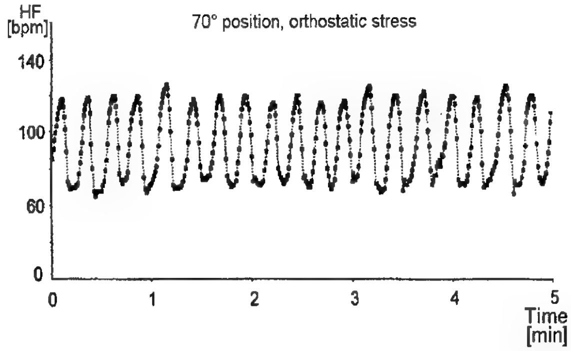

Fig. 8: HF during tilt with progressive muscle relaxation and modification of respiration

Figure 8 shows the heart frequency of a Tornado-WSO. He successfully controls his heart frequency via deep respiration combined with muscle relaxation according to E. Jacobson. This WSO has learned to keep his pulse rate in a constant range despite the orthostatic stress (70° tilt).

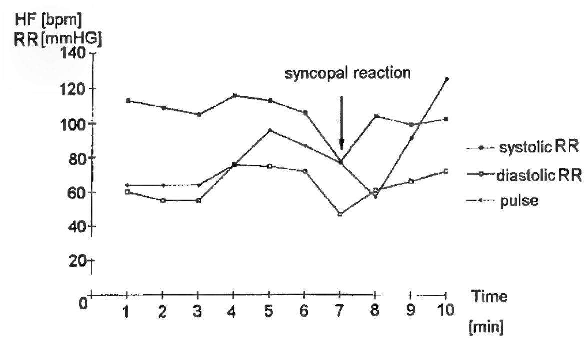

Fig. 9: Syncopal reaction: during tilt and spontanious recovery in supine position

In contrast to the above figure 9 shows heart frequency and blood pressure at a syncopal reaction of another test-person.

The orthostatic stress causes the test person to collapse because blood pressure and heart frequency drop after the change of the orientation of his body in space.

The syncopal reaction is one example for the relations between the neurocardial regulation and the reduction of the consciousness or even the loss of consciousness.

A normally harmless signal (tilt of the body) leads together with the intrinsic alarm signal (the drop of the blood pressure), to the loss of orientation, which can result in a loss of consciousness. This reaction pattern can be altered by adequate training, which has been shown before. This is an important point for the aspired training programs.

Vestibular reactions are measured by recording the eye movements in three dimensions: horizontally, vertically and torsionally together with the corresponding accelerations in the x-, y-, and z-axis.

At present we are conducting several test series to evaluate the effect of subthreshold angular accelerations. "Subthreshold" in this context means that the test person is not aware of being moved. We want to evaluate the thresholds for the beginning of counter movements of the eyes for the compensation of angular accelerations.
These thresholds will be evaluated in all three body axes, using the qualities of the FOT to conduct smooth movements in all axes.
Cerebral reactions are evaluated by brain wave recordings (topographical, quantitative EEG).
Both approaches for the use of the FOT have the common goal to avoid the Controlled Flight into Terrain (CFIT), with the help of training of the aviators as well as with the research for the causes of spatial disorientation. But they are not the only ways to use the FOT. Other fields of activity can be the development of new criteria for pilot selection and the prediction, diagnosis and/or therapy of motion sickness and "fear of flying".

Conclusion:
Training versus aeromedical research should not be a contradiction, because for evaluation and validation of training programs of the FOT aeromedical research in spatial disorientation, situation awareness and motion sickness is mandatory.

6. Appendix:

Setup: "Orthostatic-stress-test"

-	Steady state, supine (baseline)	10 min
-	Tilt, 70° in 12 s	10 min
-	Deep respiration, (inspiration 6 s, exspiration 4 s)	2 min
-	Respiration press test	1min
-	Apnoe	1 min

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Purificato R
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DYNAMIC SOCIOMETRY AND SOCIOMAPPING: NEW APPROACH TO SMALL GROUPS METHODOLOGY AND SOCIAL SYSTEMS

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SUMMARY

The original method referred in this paper enables the continual monitoring of group interactions and dynamics. We have developed this method in connection with the programme of long lasting space missions, but it could be useful in the analyses of difficult complex systems with multidimensional and rather uncertainty relations among subjects and/or objects in general, such as in all small social groups, predominantly under stress, as pilot crews and air traffis controllers shifts.

The method is based on fuzzy theory, structure analysis (pattern recognition) and mathematical topology. Plenty of various methods could be used as sources of informations - tests, expert assessment, behavioral variables, objective and subjective, quantitative and qualitative, verbal and numerical data. These informations are presented by multilevel fuzzy model of interactions. These models are agregated according to similarities in structure patterns. Discrepancies and some critical patterns are analysed as probable conflict and tension focuses.

The results of analysis are represented graphically in an user friendly pattern as a map (similar to the geographical one).

DYNAMIC SOCIOMETRY AND SOCIOMAPPING - WHAT IS IT?

Dynamic sociometry and sociomapping are research procedures used to analyze interactions between social elements (1). Such an analysis shows the social system's inner structure and dynamics of its evolution.

It is assumed that the analyzed interactions are complex and multilevel. Each relation between two represents a set of sub-relations, possibly differing from each other. If, for example, the relation in hand is the communication between two army bases, the examples of sub-relations may be the written correspondence, direct communication and communication by phone. The size and complexity of an analyzed social system may vary. Dynamic sociometry and sociomapping can be applied for an analysis of systems as small as three-member groups as well as larger groups or even as complex samples as the army or its parts. Persons, groups of persons, departments or army units may represent elements of a system.

The main feature of sociomapping is the orientation of these methods towards a broad use in the field of social management. Dynamic sociometry and sociomapping are perfectly fit for a continuous analysis of a given social system. Therefore these algorithms provide the user with a picture of the given system and its evolution changes to help make decisions and direct the development. Sociomapping provides at the same time a feedback for the decision carried out.

Sociomapping monitors the most important characteristics of the inter-elemental relations - from capturing the degree of stability and composition of these relations, their inner conflicts and disagreements, mapping the communication currents - the level of functionality in each direction, to uncovering the weaknesses in social system structure and the flaws of its dynamics' development and finally reflecting the tension build-up and short-term prediction of future conflicts.

A useful outcome of the analysis is the sociomap. Sociomap is a graphic expression of the most important information obtained by the system's analysis. In the sociomap each element is represented by an elevation point similar to one on a geographic map. The height of this point reflects the data value for the given parameter (i.e. degree of communication, social position, importance etc.). The distance between two elements stands for the level on which the relation is realized (closeness, mutual ties, cooperation). The set of contour lines and other graphic parameters provide for capturing the quality of mutual relation. A succession of maps can present comparable information to that provided by a synoptic map used in meteorology. The use of sociomaps becomes very effective after a short experience and provides a way of swift orientation even in case of analysis of complex systems.

DYNAMIC SOCIOMETRY AND SOCIOMAPPING - HOW IS IT CARRIED OUT?

I. DATA COLLECTION

It is essential to collect all relevant data for the relations analysis. Information inputs are not standardized, thus it is possible to use all available data. Methods such as document analysis, examination of audio- and videorecordings, work result analysis, testing including psycho-physiological testing, statements, direct observation, and others are frequently used.

Paper presented at the AMP Symposium on "Selection and Training Advances in Aviation", held in Prague, Czech Republic, in May 1996, and published in CP-588.

II. FUZZY CODING

Using so called fuzzy coding quantifiable data and data on scale are transferred into fuzzy models. Each pattern (data level) is represented by a fuzzy model. Each element in such fuzzy model has a fuzzy group consisting of other system elements with a degree of integrity representing the mutual relation level and its valence. A set of fuzzy models makes up a so called aggregated fuzzy model. Quality data that cannot be quantified or put to a scale are used to form so called margo models.

III. AGREGATED FUZZY MODEL ANALYSIS

An agregated fuzzy model undergoes further analysis. Different data levels are compared. Related configuration patterns are generalized by uniting the data levels. Also any outstanding discrepancies among the levels are apprehended. The most and least consistent subgroups, remarkable disproportion of relations, similarities in regarding the remaining elements of the system are pinpointed. Also a number of other expert-defined structures and parameters are searched for.

IV SOCIOMAP

Following a set rules a sociomap is produced by transforming the fuzzy model.

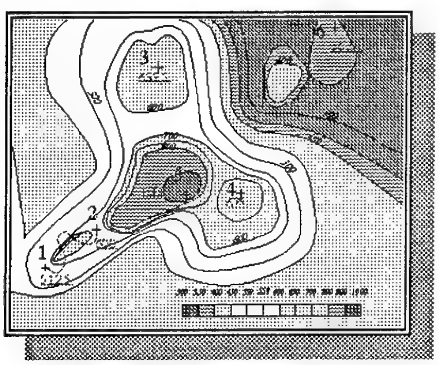

Fig. 1 Example of a sociomap.

DYNAMIC SOCIOMETRY AND SOCIOMAPPING - APPLICATION

Dynamic sociometry and sociomapping are useful on a grand scale for any social system analysis. Within the Air Force these procedures were used to gradually establish a test wing as well as for an analysis of department groups at bases, an analysis of the complete base personnel (cooperation between bases included), and an analysis of interactions between the bases and the command post.

Figure 2 shows an example of a larger system sociomap, consisting of smaller units analysis.

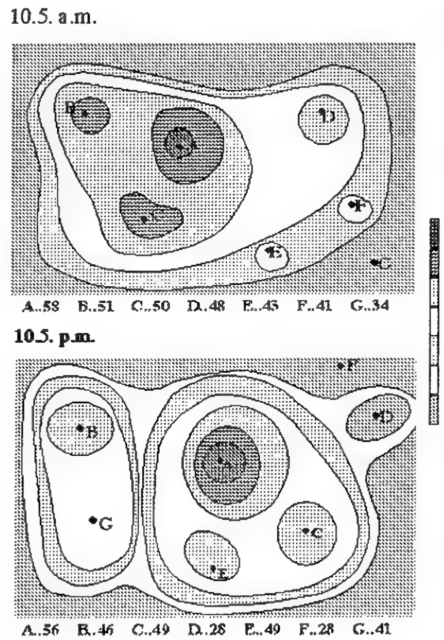

Fig. 2 Sociomap of groups.

Figure 3 shows 135-day examination of a three-member team during a space flight simulation (HUBES - ESA experiment). Overall decrease of heights reflecting the increased tensions and the following collapse of the team into a coalition of No. 1 and 2 and a solitary No. 4 are clearly displayed.

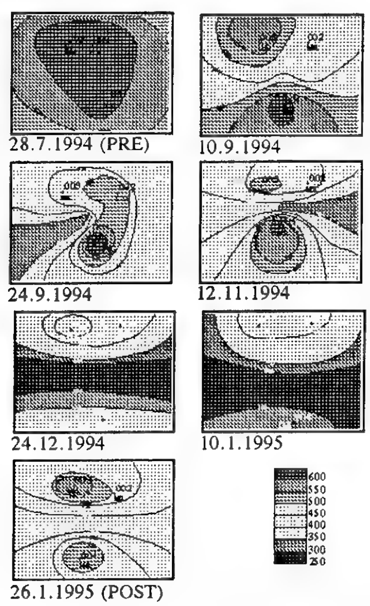

Fig. 3 Continuous sociomapping of the three-member team.

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ADVANCED SPATIAL DISORIENTATION DEMONSTRATOR
"Troop Trial" Results - *SD Illusions*

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1. SUMMARY
This paper describes five SD illusions designed to determine the capability of the ground-based Advanced Spatial Disorientation Demonstration (ASDD) to reproduce perceptual effects that normally can be produced satisfactorily only in flight. Although there were many findings during the Troop Trial Study, two appear worth special note. First, the ground-based demonstrations produced realistic motion effects (subthreshold and suprathreshold) about each axis of the gondola. In most cases, visual dominance was achieved. Second, pilot responses to each demonstration were very positive. From the pilot responses alone, this study clearly shows that the application of motion and visuals in a device like the ASDD belongs in the flight training programs. Potential of the ASDD is just now being realized.

2. INTRODUCTION
Spatial orientation is fundamental to aircraft flight. Never is the situation so evident as when flight is conducted in weather, at night, over water, over desert, or above unfamiliar terrain. The pilot must constantly crosscheck the flight instruments against the self-perception of spatial orientation generated from the position and motion cues produced by the movement of the aircraft. A portion of this instrument crosscheck is generally practiced in a nonmotion-based flight simulator. Some would even argue that motion is not necessary for flight simulation. It is the opinion of these authors, and most others familiar with the costs and countermeasures of spatial disorientation (SD), that motion cues are necessary to realistically practice and learn the true sensory conflicts experienced in flight. Pilots usually understand that what they think the aircraft is doing and what it is actually doing are often two completely different things. The controlled manifestation of this mismatch is the basis of understanding and eliminating the problem of SD. Being able to demonstrate this mismatch has been a goal of investigators for many years. We are finally approaching the ability to truly demonstrate ground-based advanced SD profiles.

History is well-marked with the attempts to develop ground-based SD training and/or demonstration devices (1). The first such device was designed in 1926, named the Ocker Box after its inventor, William Ocker. Although there were earlier devices like the Barany Chair and the Ruggle's Orientator, no one had associated the effects of these devices with the problems pilots experienced while in flight under obscure visibility. The Ocker Box marked the beginning of an international understanding of the SD problem. Interesting to note is that the device developed in 1926 is not much different from the devices still in use today. Research has identified more than 30 visual and vestibular SD illusions, yet current SD trainers successfully demonstrate only a very few--primarily vestibular ones (2). The ASDD must be capable of expanding the range of illusions, and it should require an active role (pilot in the loop) on the part of the subject.

3. ILLUSIONS
Five SD illusions were designed and evaluated for the Troop Trial Study (3). The selected illusions exercised the device's four basic degrees of motion and the simulated out-the-window scene. The degrees of motion allow for the production of both somatogravic (false sense of body tilt) and somatogyral (false sense of body rotation) effects (2). The illusions included movement below the threshold of perception, motion to generate a suprathreshold vestibular conflict between any of three degrees of motion (pitch, yaw, and roll) and the flight instruments, and a commonly known visual illusion. When the word "visual" is used in the following text, it applies to the scene displayed as the out-the-windscreen real-world picture.

3.1 Subthreshold Motion
Without frequently checking flight instruments, the pilot may miss an aircraft movement that could result in unrecognized spatial disorientation. This first SD profile was designed to demonstrate to the pilot how easy it is to experience motion undetected by the vestibular system.

Paper presented at the AMP Symposium on "Selection and Training Advances in Aviation", held in Prague, Czech Republic, in May 1996, and published in CP-588.

While the pilot observed a visual (out-the-windscreen) scene typical of a visual condition often seen in flight (a solid cloud deck below and high thin cirrus clouds above), the cockpit was slowly moved about the planetary axis with a coordinated movement about the longitudinal axis. The net gravitoinertial force vector remained perpendicular to the bottom of the seat. No flight instruments were displayed. Once established in a bank of approximately 30 degrees at a planetary speed of 14 rpm, the pilot was asked to report perceived bank. After the report, the actual bank was shown to the pilot. The pilot was asked to describe the sensation.

Subthreshold Motion demonstrates shortfalls to the pilot who is relying only on seat-of-the-pants input. In addition, this subthreshold demonstration, because of the cloud bank, illustrates the ease of confusing a false visual horizon with the actual aircraft attitude. This demonstration is probably more of an eye-opener to someone watching the device from outside. It is quite impressive to see the cab rotating at 14 rpm and the pilot in the cab reporting he/she feels as if they haven't moved.

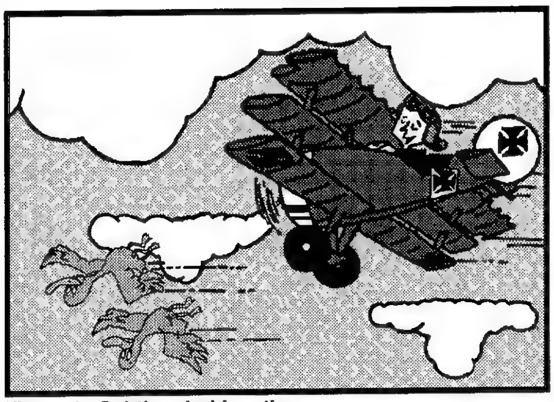

Figure 1. Subthreshold motion.

3.2 False Pitch

The False Pitch demonstration begins with unrecognized SD and ends with recognized SD. It demonstrates how difficult it is to overcome a vestibular illusion with just a typical flight instrument.

In flight, a pilot constantly estimates the pitch of the aircraft. If precise pitch is required, the pilot must look at the attitude indicator and make appropriate adjustments. Anytime the aircraft is either accelerated or decelerated, the pilot can misperceive actual pitch (e.g., the more the acceleration, the more overestimation of a pitch up). Given control of the aircraft, the pilot may inadvertently push the nose down and actually descend, while thinking the aircraft is still in a climb. If recognized, the pilot experiences Type II, SD (2).

To demonstrate how easy it is to misperceive the pitch of the aircraft, we designed a night-time takeoff scene. Planetary movement produced radial acceleration which is interpreted by the pilot as longitudinal acceleration (with the help of a visual runway scene and counter-rotation of the cab). The cab accelerates to 14 rpm with the nose radially inward, while a visual scene shows the aircraft rolling down the runway. Shortly after visually getting airborne, the visual scene disappears, and the pilot is given control of pitch and asked to respond with a pitch input to return to his/her perceived level attitude.

After establishing a perceived level attitude, the true-reading attitude indicator is displayed and the pilot is asked to return the cab to the instrument depiction of level flight (using the attitude indicator for reference). The pilot now perceives a return to the climb situation due to the force exerted on the otolithic membrane, even though the attitude indicator shows the contrary. Flight instruments did not break the illusion! Being able to experience this visual/vestibular conflict is critical to the pilot's overall attitude awareness training.

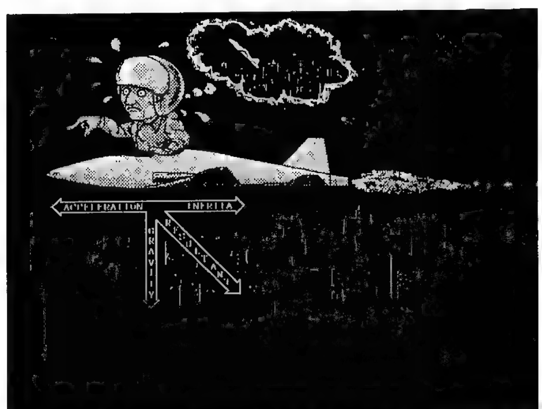

Figure 2. A somatogravic illusion occurring on takeoff.

3.3 False Yaw

False yaw (the oldest SD demonstration) begins with unrecognized SD, transitions through recognized SD, and ends with a demonstration of the visual system overcoming the perception created by the motion of the cab (visual dominance). Even though yaw is seldom considered a problem in modern aircraft, the USAF still experiences a few yaw related mishaps. Perhaps, as aircraft become more maneuverable, the yaw problem may resurface. USAF Undergraduate Pilot Training (UPT) requires trainees to be proficient in spin prevention and to safely recover from actual spins.

Historically, the Graveyard Spin has the pilot inadvertently maneuvering the aircraft back into a spin after initially

recovering from a sustained spin. During recovery, the sudden apparent reversal of the aircraft's yaw causes the pilot to apply rudder opposite to the direction needed, thereby returning to the spin and, if not corrected, impacting the ground--hence the name graveyard spin. The pilot's spatial orientation at this time is obviously an unrecognized (Type I) situation.

In the ASDD, the cab initially yaws while the pilot verbally responds to the sensations. No visuals are available. After the yaw reaches a constant rate, the cockpit is perceived to have stopped. Once established in a perceived zero yaw rate, the yaw is slowed, producing the apparent reversal of rotation. At this point the horizontal situation indicator (HSI) is shown to the pilot, demonstrating the difference between perceived yaw and actual yaw. While the pilot is confronted with the conflict between the HSI flight instrument (seen moving in one direction) and his/her rotational orientation percept (felt in the opposite direction), the visual scene is displayed, which quickly eliminates the conflict. The pilot now experiences firsthand, how quickly the visual system overrides the vestibular sensation!

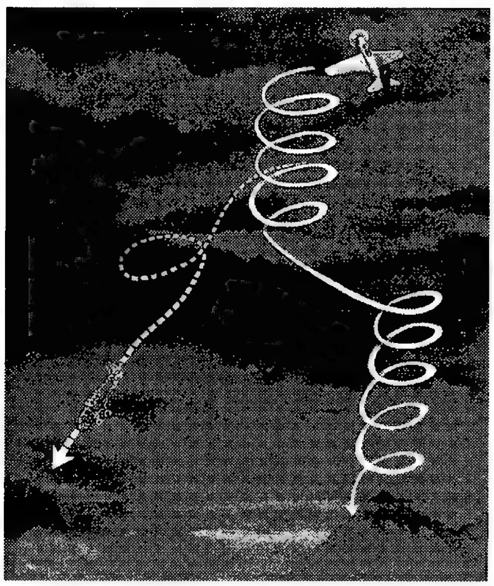

Figure 3. The graveyard spin.

3.4 False Bank

The false bank illusion comprises both somatogyral and somatogravic principles. A false sensation of bank is difficult to reproduce because it requires synchronized movement about all four axes, and the pilot must usually lose the sensation of an initial bank--an event difficult to duplicate on the ground. In flight, when a bank occurs, the pilot may, for various reasons, change to another bank without checking the flight instruments. The pilot then inadvertently increases bank without an increase in back pressure. The result is a descending spiral. Unfortunately, although the effect is well understood, this unrecognized SD illusion known as the Graveyard Spiral is still a familiar killer to the flying community.

During this profile, the pilot experiences a level, 30-degree banked turn, while the cab is rotating tangential at 15 planetary rpm. The visual condition is at night without the use of flight instruments. Once established in the turn, the visuals are removed and the pilot is presented with a false perception of roll. When exposed to the false bank, the subject is asked to describe the stick input needed to return to initial banked conditions. Even though the pilot may think the cockpit has reduced its bank, the actual bank never changed from the initial bank of 30 degrees. Had the subject increased bank and rolled the cab to maintain a perceived 30 degree bank turn, the aircraft would have actually banked greater than 30 degrees and would have begun a descent because of no increase in back pressure to compensate for the loss of lift.

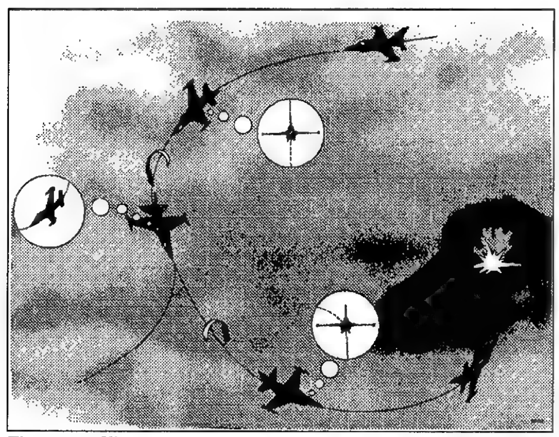

Figure 4. The graveyard spiral.

3.5 Visual Illusion

Visual illusions are more of a threat to produce SD than most pilots would be willing to admit. There are many visual illusions to demonstrate, but none more threatening and dramatic than an illusion during the approach to landing. This final illusion was designed to show the pilot how easy it is to misperceive actual position and motion due to unrecognized misalignment from limited visual information (e.g., in the clear, at night). This effect has been termed a Black-Hole Approach or sometimes called the "Duck-under approach due to the actual flight path.

Four final approaches are presented to each subject, the first three of which are automated and the last of which is flown by the pilot. During the first approach only (in simulated daytime conditions and with flight instruments), the approach is halted at decision height and the pilot is asked to observe the visual features. On the second approach, all conditions remain the same except the visual scene is now depicted at night and the flight instruments are removed. The pilot is asked to call decision height. During the third automated approach, the visual runway is now 1/2 the original size (at night) and the background slightly tilted up, simulating an upsloping terrain. The pilot is asked to report the decision height. When the aircraft reaches the called decision height, the system is "paused".

The fourth and final approach is actually flown by the pilot, however, the visual content of this approach varied from the previous approach by slightly upsloping the narrow runway. The actual aimpoint is about 1.5 miles short of the runway. The fourth approach is also recorded in a profile depiction and printed to show the pilot a comparison between a normal 3 degree approach and their own "Duck-under" approach.

Figure 5. Black hole approach.

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Informational Technology for Modelling of Fighters Medical Testing Procedures by Centrifuge Accelerations

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1. SUMMARY

Computer informational technology (CIT) for use in airspace medicine for solving main problems, connected with the problem of provision human with tolerance to dynamic piloting accelerations, is offered. The base of the CIT is the specialized complex of mathematical models (CMM), which includes models of human hemodynamics (MHH), factors models of external loading (MELF) and models of protections (MP). MHH consists of three independent models: model of heart pump function, model of hemodynamics in branching vascular net (in of view of regional peculiarities self-control mechanisms), model of central nervous-reflector control mechanism of heart pump function (by changes of heart rate and inotropism) and vessels' tonus (by change their resistance, capacity and unstress volume). MELF describes main physical effects of external factors (anti-G suits, breathing pressure, muscle stress, values of angles between gravitational vector direction and parts of human body in sitting position) on human hemodynamics. Besides, this model also includes description of different profiles of accelerations.

The adequacy of proposed models to piloting accelerations was proofed for some standard testing situations, including use of different protections. For muscle relax situation and with acceleration increase gradient 0,1g/s tolerance about 4,0g was shown. After use of anti-G suit (50 mm Hg/g) and under breathing pressure (5mm Hg/g) tolerance increased to 7,8g. In addition to control of characteristics of heart inotropism and rate, mean transmural pressure in aortic arch, in the scope of proposed CIT it is possible to control blood flows, pressures and blood volumes in main body sections (cranial, thoracic, abdominal, hands, thighs and shanks).

The CIT is oriented on physiologists-experimentators. Using proposed technology they can easily realize almost all actual situations, which take place during centrifugal researches. Computer simulations give to researchers a lot of new possibilities for study of potential effects of different changes of characteristics of physiological mechanisms and use regimes of external loadings and protectors. One of main advantages of proposed CIT consists in essential economy of requested for centrifuge researches financial resources. This economy is reached by the way of replacing the part of empirical researches by its computer imitations. In presented variant CIT is realized as a software for IBM-compatible computers for the use under Microsoft WINDOWS environment.

2. LIST OF SYMBOLS

$i = 1$	right heart
$i = 2$	left heart
P_i^{INP}	input pressure
H_a^V	distance between atrical and venticular centers
N^G	coefficient of gravitational overload
φ	gravitational vector deflexion angle
P_i^{FD}	end-diastolic pressure
ρ, A, B	aproximation constants
Q^i, Q^o	input and output flows respectively
r_1, r_2	open and close valve resistances
ΔP_k	pressure difference on both valve sides
P_{KP}	necessary for valve opening pressure
P_{KO}	necessary for valve closing pressure
T_L	diastola's prolongation
C	diastolic elasticity of ventriculas
V	strained volume
F	heart rate
k	inotropic coefficient of ventricula.
P_j^I, P_j^E	intra- and extra- vascular pressure
P_j^T	transmural pressure $P_j^T = P_j - P_j^E$
U_j	non-strained blood volume
V_j	section blood volume
D_j	volume rigidity
R_{jl}	hydravlic pressure between j-th and l-th compartments
q_{jl}	their blood flow
δ_M	sensetiveness of selfcontroling mechanizm

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P^C	mean pressure in carotid arteries
K_j^O, K_j^I	output and input coefficients of compartment orientation
φ_j	angle between j compartment and horizontal
h_j	length of compartment
ρ_j	density of blood
P_j^G	gravitational component of pressure
K^E	coefficient of transmission P^E into vessel
F_j^R	level of mechanoreceptor activity
P_j^R	transmural pressure
P_j^t	thresholds of receptors activity
X_j	control parametres of CVS
E_v, E_s	activity of N. vagus and N. sympathicus
F_A, K_A	levels of F and K under automatic regime of heart
a_i, b_i, p_j	constants
d_1, d_1^u, β	constants
P^I	innere (tissue) extravascular pressures in each sections of anti - G suit
P^E	air pressure in sections of anti - G suit
P_m	mean muscle pressure
g_m^{th}	threshold of acceleration for muscle stress start
g_T^{th}	threshold of acceleration for anti - G suit initiaton
g_{BP}^{th}	threshold of acceleration for start of breathing pressure increase
P_m	mean muscle pressure
P_{p_0}	intrapleural pressure under human supine position
P_p	intrapleural pressure under other human positions
α_{BP}	gradient of breathing pressure increase

3. INTRODUCTION

The uninterrupted perfection of flight characteristics of fighter aircraft requests appropriate modification of procedures and methods of provision the pilots' tolerance to piloting accelerations [1,2,4,5,13]. Until recently this problem was solved only empirically by the means of regular testing of pilots with special centrifuges. The problem, therefore, requests essential financial expenditures and often is connected with a risk to health [1,16]. Further keeping to this way is not justified. Recent computers have reached enough power to provide alternative way for solving the problem. If we create adequate mathematical models (MM) for description of all main processes in human hemodynamics during centrifuge accelerations, we can transform these models in computer informational technology (CIT). Using CIT, physiologist-researcher can plan a strategy of study problem such way, that it may be possible to substitute a part of expensive nature experiments by computer simulation.

Such view on this problem is not new, however, until recently MM adequate enough to describe all system hemodynamics during accelerations was not proposed. Some models were created for study intracranial blood circulation under +Gz accelerations. Some times ago one MM [6-10] was proposed for simulation study of human baroreflector control mechanism under postural changes. After it detail research and step by step perfection, the scope of it use have expanded significantly. Complete MM of human hemodynamics under piloting (centrifuges) accelerations and the special CIT, based on this MM, will be described in this paper for the first time.

4. GENERAL CONCEPTION OF CIT

General conception of creation and use the proposed CIT is showed on *fig.1.* The basic model complex (BMC) includes three models: model of nervous control of cardio-vascular system, model of heart pump function, model of hemodynamics in branching vascular net (this net showed on *fig.2.*). CIT's user with the help of easy in use user interface can choose and tune the BMC and all regimes for acceleration profiles and switch on protections. The special program module lets user to tune the model of nervous control of hemodynamics and choose one of proposed hypotheses concerned mechanism of arterial and nonarterial mechanoreceptor reflexes. Physiologist can check, how human hemodynamics after specified changes of gain of baroreflector mechanisms from aortic arch and carotid sinus for heart or vessels controlling parameters may be changed. Besides, he can also verify the quantitative central hemodynamics effects caused by different changes of regional vessel tonus.

The results of computer simulation experiment are presented to user both in table and graphs forms. It is possible to save all results, to compare current results with previous. Although, proposed variant CIT realizes hemodynamics only under accelerations +Gz, we also have MM for description of hemodynamics under combined accelerations in three-dimensional vascular net [6]. We can also modify basic model complex such way, that individual antropo-morphological characteristics of human will be taken into consideration.

The *fig.2.* illustrates the form of cardio-vascular net (CVN) in basic model complex, that uses multicompartmental presentation. According to this presentation, CVN in model is different arterial or venous compartments with different levels of height over the ground. Every compartment has its own volume, unstress volume, elasticity, extravascular pressure, angle relative to horizon, length. This CVN is minimum one, that lets us to define all specified human positions and gives us possibility to analyze dynamics of blood flows, blood pressures and summary volumes in cranial, thoracic, and abdominal cavities, in hands and different parts of legs. The main mathematical relations for description of heart pump function, hemodynamics in CVN and function of nervous-reflector control system are described bellow.

4.1. Model Of Heart Pump Function

Model of heart pump function discloses main relation between mean cardiac output and central venous (for right heart) or lung venous pressures (for left heart). Additional factors, that are taken into consideration, are: heart rate and inotropic coefficient of ventriculeas (it reflects almos linear relation between ventriculeas end-diastolic volume and stroke volume for wide changing t

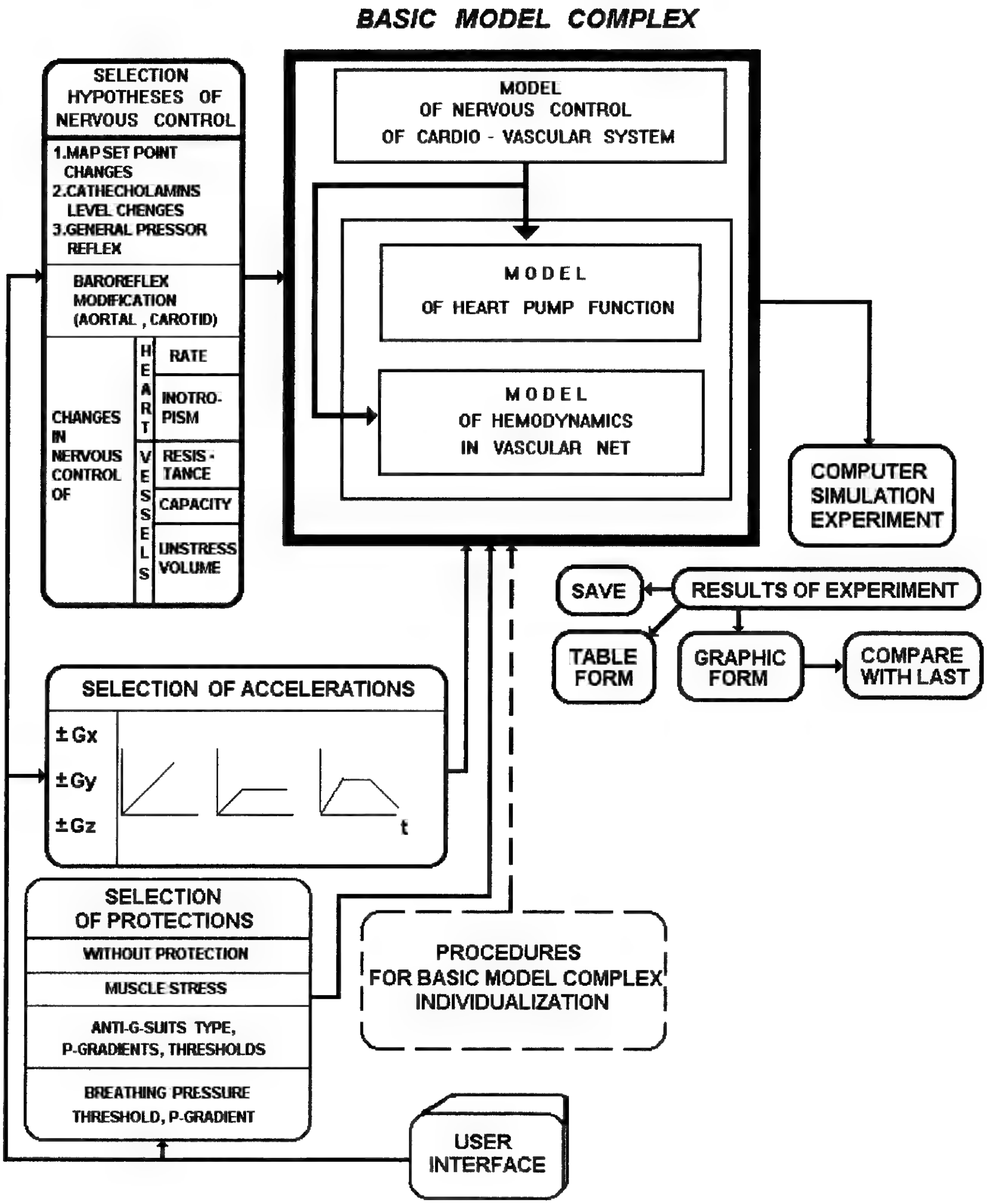


Fig.1. General Conception of Human Hemodynamics Computer Modelling During Piloting Accelerations.

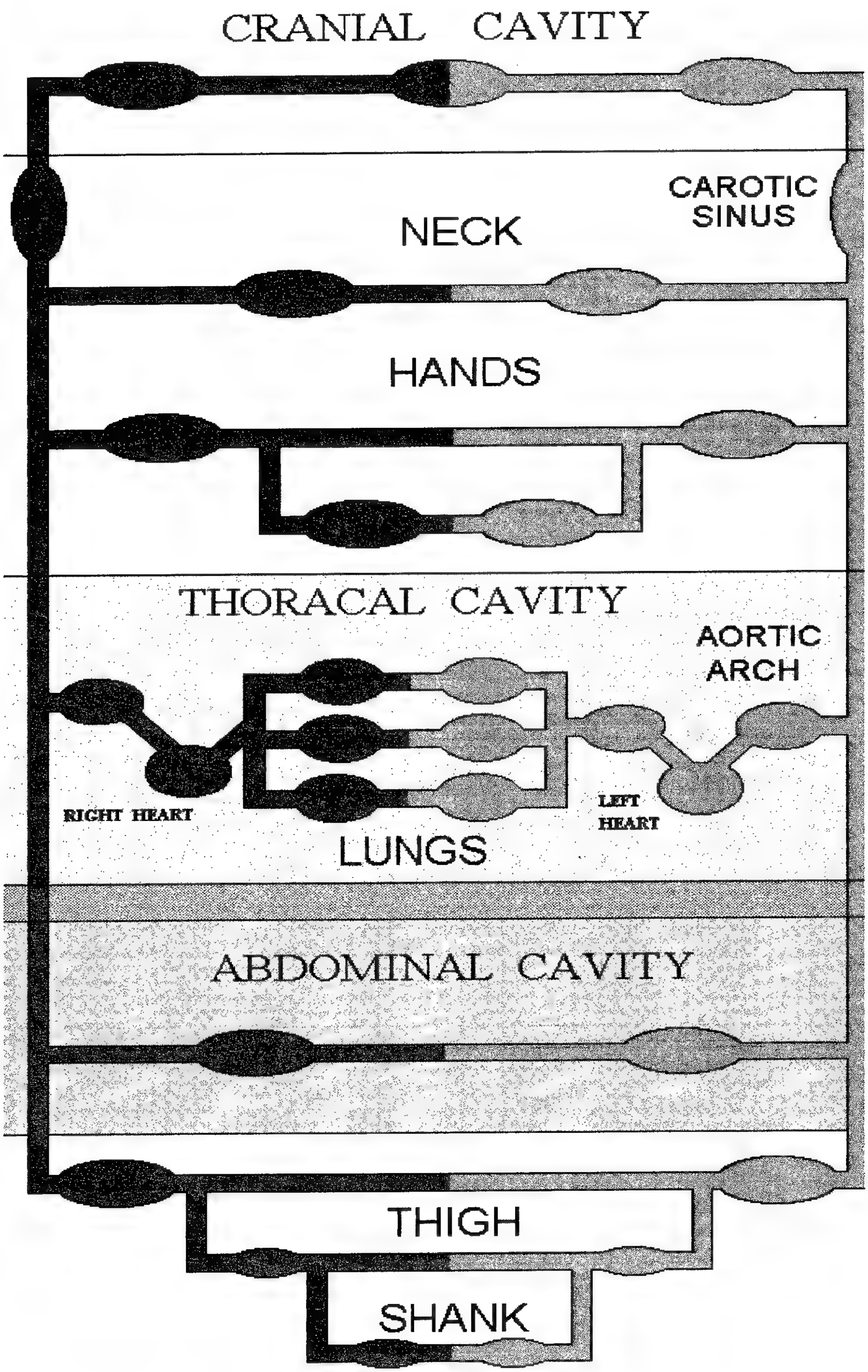


Fig.2. Cardio-Vascular System in Model.

range of venous input pressure [10]); resistance of atria-ventricular valves; diastolic elasticity and unstress volume of ventriculeas; prolongation of diastola:

$$Q=\frac{F\cdot k_i\cdot\left[\left(\Delta P_{ai}^{V}\cdot C_i+U_i\right)-U_o\right]\cdot\left[1-exp\left(-\frac{T_L}{R_{aVi}^{K}\cdot C_i}\right)\right]}{1-\left(1-k_i\right)\cdot\left[1-exp\left(-\frac{T_L}{R_{aVi}^{K}\cdot C_i}\right)\right]}$$

$$P_{ai}^{V}=P_i^{INP}+0.73\cdot\rho\cdot H_a^{V}\cdot N^{G}\cdot sin\,\varphi-P_i^{FD}$$

$$T_L=\frac{1}{F}\cdot A+B\cdot(1-k)$$

$$P_i=\begin{cases}0, V_i\le U_i\\ \frac{(V_i-U_i)}{C_i}, V_i>U_i\end{cases}$$

$$V_i(t)=V_i(0)+\int_0^t\left(Q^I-Q^O\right)dt$$

$$R_{aV}^{K}=\begin{cases}r_1, \Delta P_K>P_{KP}\\ r_2, \Delta P_K\le P_{KO}\end{cases}$$

4.2. Model Of Hemodynamics In Branching CVN

Basic dependencies for modelling of hemodynamics in branching CVN are static nonlinear dependencies between transmural pressures and blood volumes in each i-th vessels' compartment. These dependencies are altered for different arterial or venous vessels. In the model these nonlinear curves are approximated by piecewise-linear, including three parts, that reflect changes of vessels' lateral section [10]. According to this approximation, P-V dependence looks as:

$$P_i^T=\begin{cases}\left(V_i-U_i\right)\cdot D_{0i} & ,V_i<U_i\\ \left(V_i-U_i\right)\cdot D_{1i} & ,U_i\le V_i\le U_{1i}\\ \left(U_{1i}-U_i\right)\cdot D_{2i}+\left(V_i-U_i\right)\cdot D_{1i} & ,V_i>U_{1i}\end{cases}$$

Blood flows between j-th and l-th vessel compartments, which are connected by means of hydraulic resistance R_{jl}, are defined as separate pressure gradients (G_{jl}^P) on R_{jl}. Transmural pressures, external pressures P^E and hydrostatic pressures P^G are viewed as the factors, which determine G_{jl}^P. Coefficients for P^E reflect differences for levels of vessel's locations and transmission characteristics of different vessels' environment (muscles, cavities, skin):

$$q_{jl}=\frac{G_{jl}^P}{R_{jl}}$$

$$G_{jl}^P=\left(P_j^T+K_j^e\cdot P_j^E+K_j^O\cdot P_j^G\right)-\left(P_l^T+K_l^e\cdot P_l^E+K_l^I\cdot P_l^G\right)$$

$$K_j^O=\begin{cases}1, & sin\,\varphi_j>0\\ 1, & sin\,\varphi_j>0\end{cases};K_j^I=1-K_j^O$$

$$P_j^G=N^G\cdot\rho\cdot h_j\cdot sin\,\varphi_j$$

For collapsible vessels:

$$q=\frac{\left(P_1-P_2\right)\cdot 2a^3\cdot b^3}{\left(a^2+b^2\right)}$$

$$R_1=\begin{cases}R_0\cdot\left(\frac{V_0}{V}\right)^2 & ,P^T>P_0\\ R_0\cdot r_0^4\cdot\frac{a^2+b^2}{2a^3\cdot b^3} & ,P_1\le P^T\le P_0\\ R_1 & ,R_1>>R_0,\ P_1<P_0\end{cases}$$

$$a=\frac{V\cdot r_0^2}{V_0\cdot b}$$

$$b=\frac{1}{3}r_0\cdot\left[d+2\cdot\left(1+\sqrt{1-2d^2+d}\right)\right]$$

$$d=\frac{V}{V_0}$$

$$R=R_u\cdot\left(\frac{U}{V}\right)^2$$

$$V_0=V|_{p=0}$$

Self controlling mechanism of brain flow is described as:

$$R^{AM}=\begin{cases}R_{min}^{AM} & ,P^{AM}\ge P_{max}^{AM};\ \ P_{min}^{AM}<P^{AM}<P_{min}^{C}\\ R_{max}^{AM}\cdot C & ,P_{max}^{C}<P^{AM}<P_{max}^{AM}\\ \frac{E_1}{P^{AM}} & ,0\le P^{AM}\le P_{min}^{AM}\end{cases}$$

$$C=\left[1-exp\left(X_i\cdot\left(P^{AM}-P_{max}^{AM}\right)\right)\right]$$

$$\frac{d\,R^{AM}(t)}{d\,t}=\frac{\delta_M\cdot P^{AM}(t)-R^{AM}(t)}{T_m}\quad ,P_{min}^{C}<P^{AM}<P_{max}^{C}$$

Function of venous valves:

$$R_{jv}=\begin{cases}R_{1j} & ,q_j>0\\ R_{2j} & ,qj\le 0\end{cases},R_{1j}>>R_{2j}$$

Dynamics of blood volumes in compartments described by the next equations:

$$V_j(t)=V_j(0)+\int_0^t\left(q_j(t)-q_l(t)\right)dt$$

$$\sum_i V_i(t)=\text{const}\sum_i V_i(t)=\text{const}$$

4.3. Models Of Nervous-Reflector Control Of Hemodynamics

We have developed several variants of model for description of main physiological characteristics of central nervous-reflector control processes [7,8,10]. Although their differences are not of principle for solving most of problems of applied physiology, we think there are some reasons to pay attention to these differences in the paper. To analyze they will be useful to take a look on *fig.3*, that discloses the scheme of principle of cardio-vascular system reflector control under +Gz accelerations.

We can see that there are two heart control parameters (F,k) and three vessels integral control parameters (D,U,R). The last three parameters are dispersed on different regional vessels' area, according to existing physiological notions about efferent sympathetic nervous density.

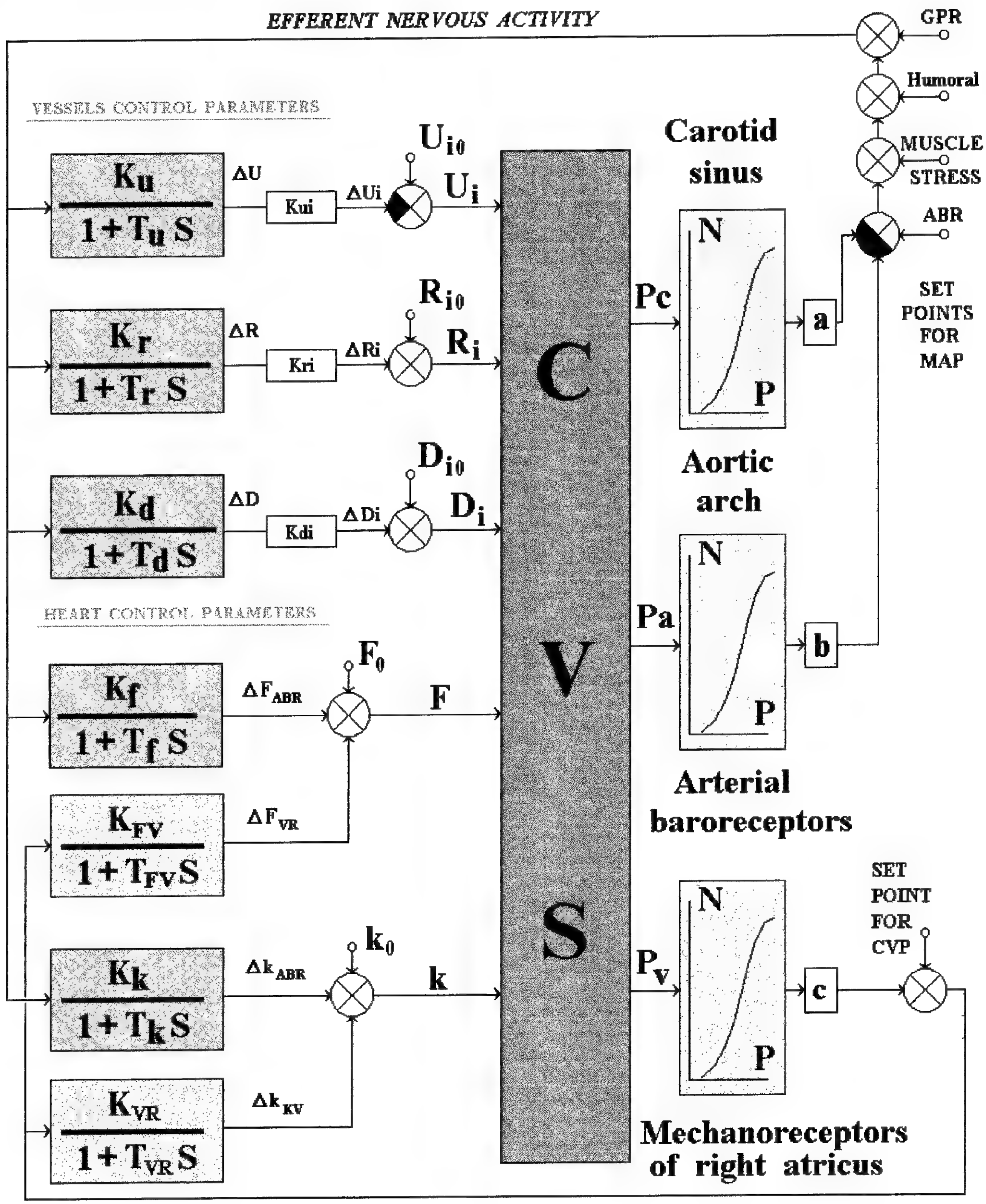


Fig.3. Hemodynamics Control Model.

In this scheme there are two different feedback channels: first - negative for arterial baroreceptor reflexes (ABR) and another - positive for mechanoreceptor reflex from area of right atria (this reflex is known as Bainbridge's reflex). The last one can change only F and k. If ABR is often included in different models of hemodynamics control, the Bainbridge's reflex is presented in models seldom . But there are sufficiently reasons to involve it in our hemodynamics model under piloting accelerations. We mean essential increase of central venous pressure during special breathing procedures, muscle stress or use of extendent coverage anti-G-trousers [1,3,4,11-14]. The nervous activity in both feedback channels is formed as difference between set-points level and summary activity of receptors. ABR is presented in the model as nonlinear dependencies between arterial transmural pressures in aortic arch and carotid sinus and their summary baroreceptor activity. These dependencies take into consideration all known peculiarities of distinctions between threshold pressures and activity of baroreceptors from both zones [7,9,10]:

$$F_j^R = \frac{1 - exp\left(\beta_j^R \cdot \left(P_j^R - P_j^t\right)\right)}{1 + B_j \cdot exp\left(\beta_j^R \cdot \left(P_j^R - P_j^t\right)\right)}$$

$$\frac{d\,\Delta X_i(t)}{dt} = \frac{K_i(t) \cdot E(t) - \Delta X_i(t)}{T_i}$$

$$K_i(t) = \begin{cases} K_i^P \cdot \left[X_i^{max} - X_i(t)\right] & , E(t) > 0 \\ K_i^d \cdot \left[X_i(t) - X_i^{min}\right] & , E(t) \le 0 \end{cases}$$

$$X_i(t) = X_{oi} + M_{ij}^1 \cdot \Delta X_i(t)$$

$$E_j = P_j - p_j$$

$$X_i(t) = XB_i^{min} + \sum_{i=1}^{n} \Delta X_i(t)$$

As was showed during preliminary researches of models [9,10], we can not specify the characteristic behavior of heart rate and provide the hemodynamics tolerance to +Gz more than 4,0g, remaining in the frames of classic notions of nervous-reflector ABR control of CVS only. Aortal and carotid baroreflexes may be presser or depressor, depending on a level of local transmural pressures [7-10]. During +Gz accelerations the interaction between aortal and carotid baroreflexes may be inverted from synergetic to antagonistic. Antagonistic interaction takes place when the mean transmural pressure in carotid sinus becomes lower than the one under g=1,0, and the mean transmural pressure in aortic arch exceeds its level under g=1,0. Since that moment summary effect of ABR will be less than one, when both reflexes are presser. As a hemodynamics result in this situation we will see that both of heart and vessel's parameters begin to decrease. Such behavior of parameters is resulted in decrease of mean arterial pressure, and, thus, human tolerance to +Gz accelerations could be higher. Because we know that humans +Gz tolerance is essentially more than 4,0g, we must think also about other reflexes, that can modify effects of ABR. As one of such possible reflexes we included in our model general presser reflex (GPR). It is necessary to outline that GPR is a hypothethic reflex only, about which we can not find almost nothing in special literature. We can only suppose about mechanisms of its activity. Because the mean brain flow does not essentially decrease under this conditions, we assume that GPR may be initiated by different mechanoreceptors of overstretching structures (muscles, diaphragm, organs in thoracic and abdominal cavities).

Besides described peculiarities this model also takes into consideration changes of arterial set point level. They may be initiated by both muscle activity and level of cathecholamines.

Each channel of reflector changes of control parameters has its gain (K_i) and time constant (T_i). K_i characterizes power, when T_i - inertia of reflector processes. By changes of these parameters we can simulate various conceivable situations. It is necessary to note that every K_i is not constant value. Between K_i and control parameters (X_i) there are functional relations: K_i decreases when the parameters increase and their functional reserves decrease.

According to second model of CVS reflector control there are no set points for control of arterial pressure. All baroreflector processes are possible due to reciprocal relation between arterial baroreceptor activity (from one side) and efferent sympathetic and vagus neuronal activities (from other sides). The crosspoint of these curves defines current level of efferent nervous activity and vessels and heart parameters values. Appropriated equations for this variant of model follow:

$$E_s = \frac{(1 + H_s) \cdot exp\left(-H_s^1 \cdot S\right)}{1 + B_s^T \cdot exp\left(-H_s^1 \cdot S\right)} ,$$

$$E_v = \frac{b_v \cdot exp(b_s \cdot S)}{1 + d_v \cdot exp(b_s \cdot S)}$$

$$S = \sum_{j=1}^{5} W_j \cdot F_j(PP_j)$$

$$F_j^R = \frac{1 - exp\left(\beta_j^R \cdot \left(P_j^R - P_j^t\right)\right)}{1 + B_j \cdot exp\left(\beta_j^R \cdot \left(P_j^R - P_j^t\right)\right)}$$

$$F(t) = FA + KF_s \cdot E_s(t) - KF_v \cdot El_v(t)$$

$$k(t) = kA + Kk_s \cdot E_s(t) - Kk_v \cdot E_v(t)$$

$$D_a = D_a^s \cdot E_s\ ,\quad D_v = D_v^s \cdot E_s$$

$$V_p = V_s - U = \begin{cases} d_1 \cdot (a_2 \cdot E_s + b_2) & , E_s > 4 \\ d_1^u \cdot (a_3 \cdot E_s + b_3) & , E_s \le 4 \end{cases}$$

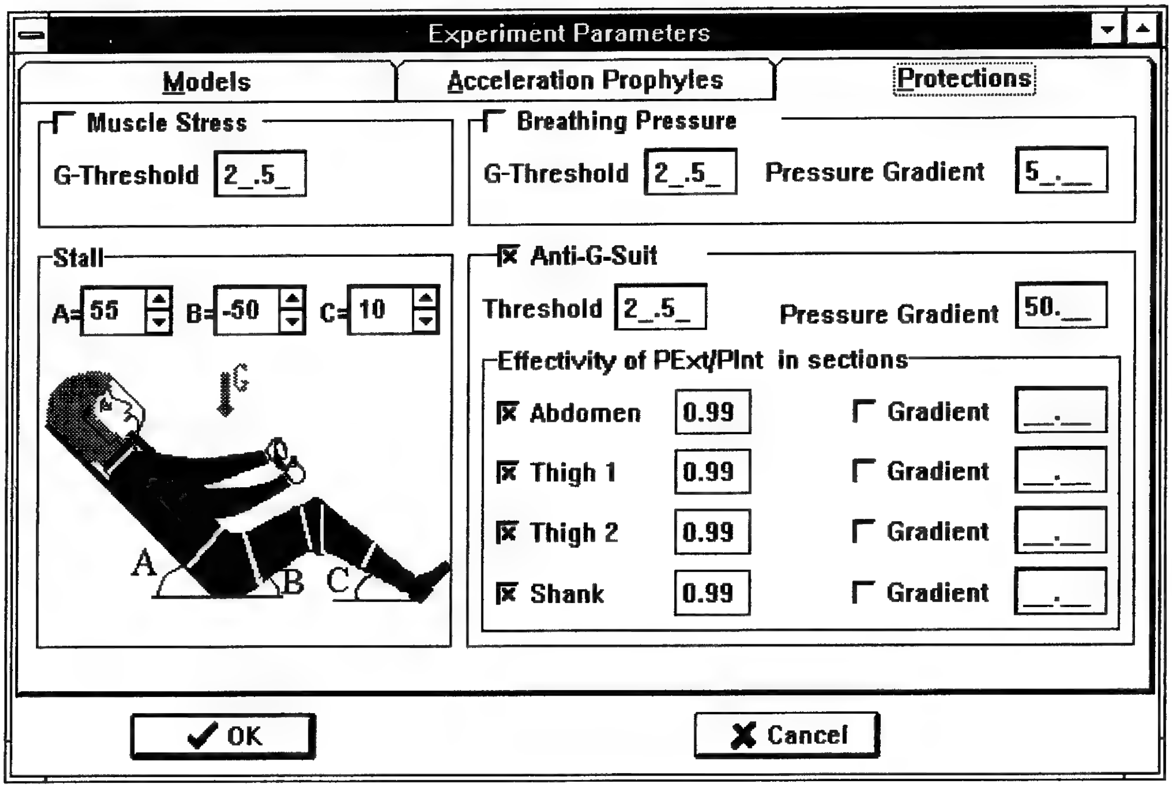
5. MODELS OF PROTECTIONS

To describe main hemodynamics effects of use anti-G-trousers in model we assume that the pressure transmission process from sections of trousers into tissue around vessels may be presented in first approximation with the help of this differential equation:

$$T \cdot \frac{d\,P^I(t)}{dt} = K\left(P^I(t)\right) \cdot P^E(t) - P^I(t) \quad , g \ge g_T^{th}$$

$$P^I(t) = 0 \quad , g < g_T^{th}$$

where T -time constant and K- transmission coefficient of different human body cavities or tissues, g_T^{th}-level of threshold +Gz.



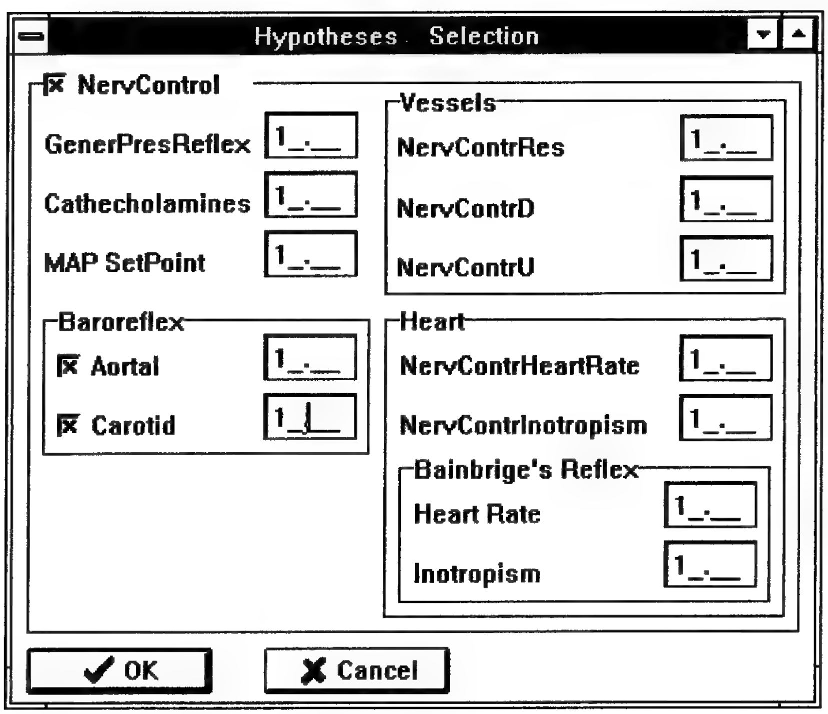


Fig.4. General View of User Interface for Selection of Experiment Parameters

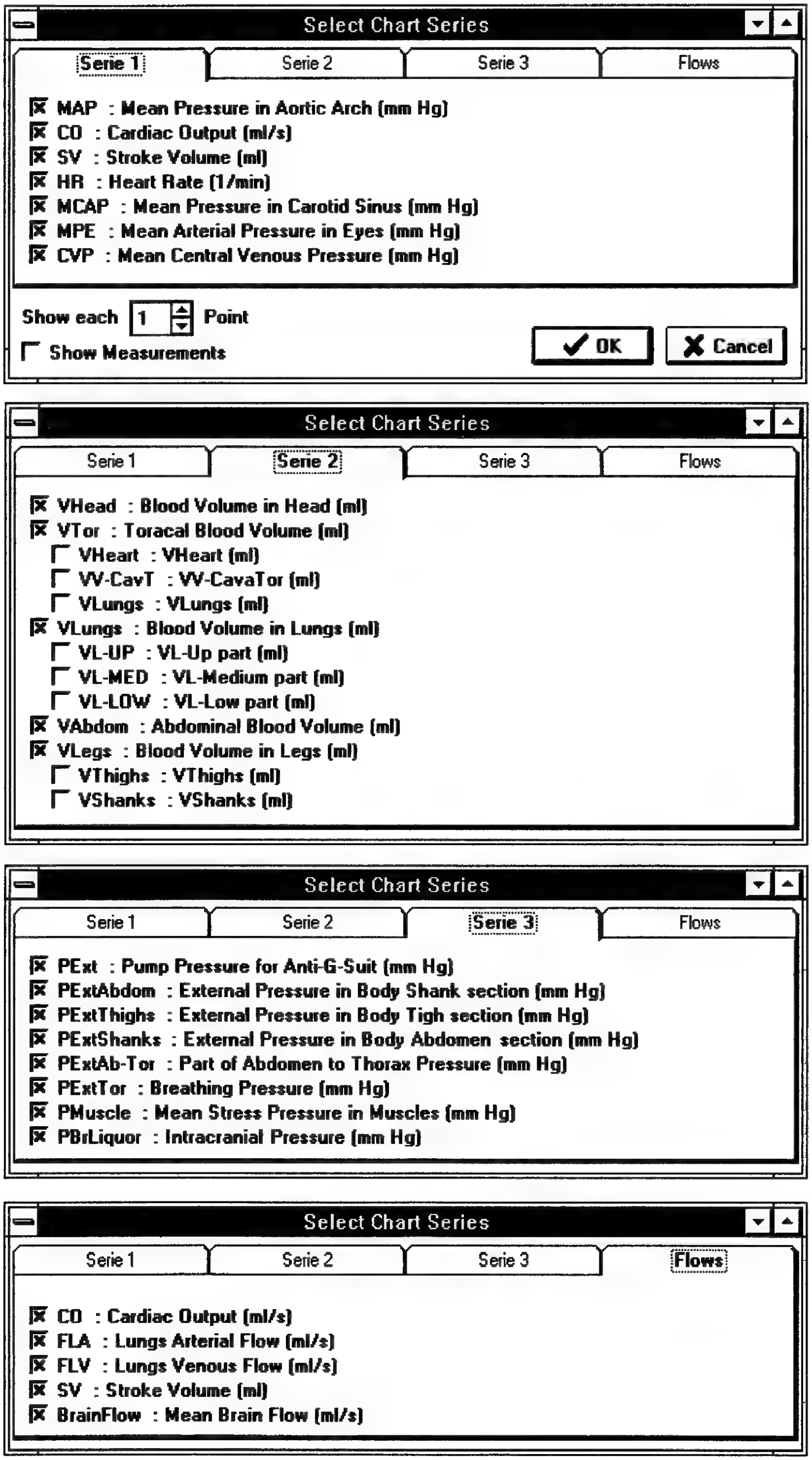


Fig.5. Computer Screen Forms for Select Chart Series

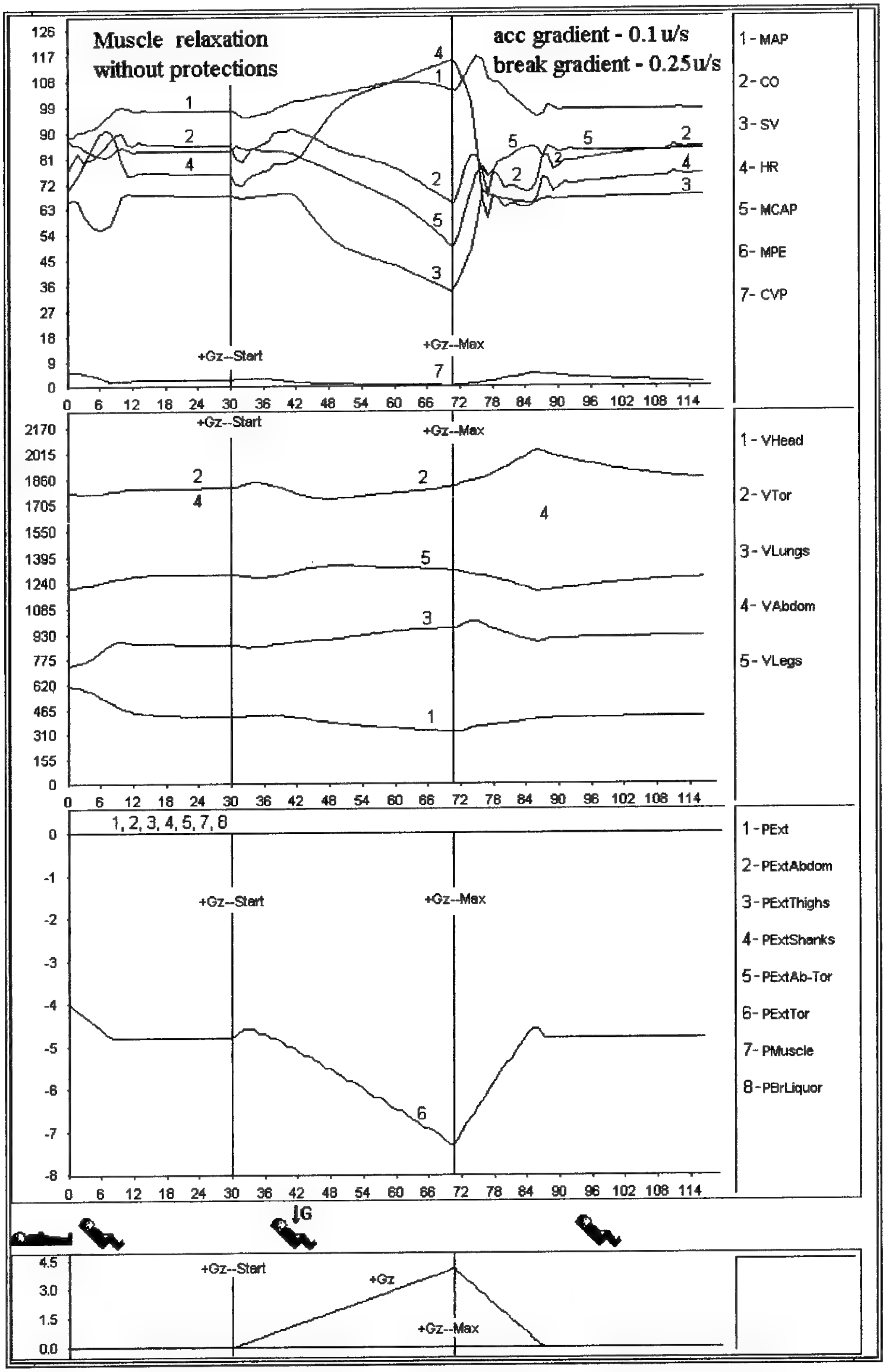


Fig.6. Dynamics of Main Control Parameters During Computer Experiments under Muscle Relaxation Condition

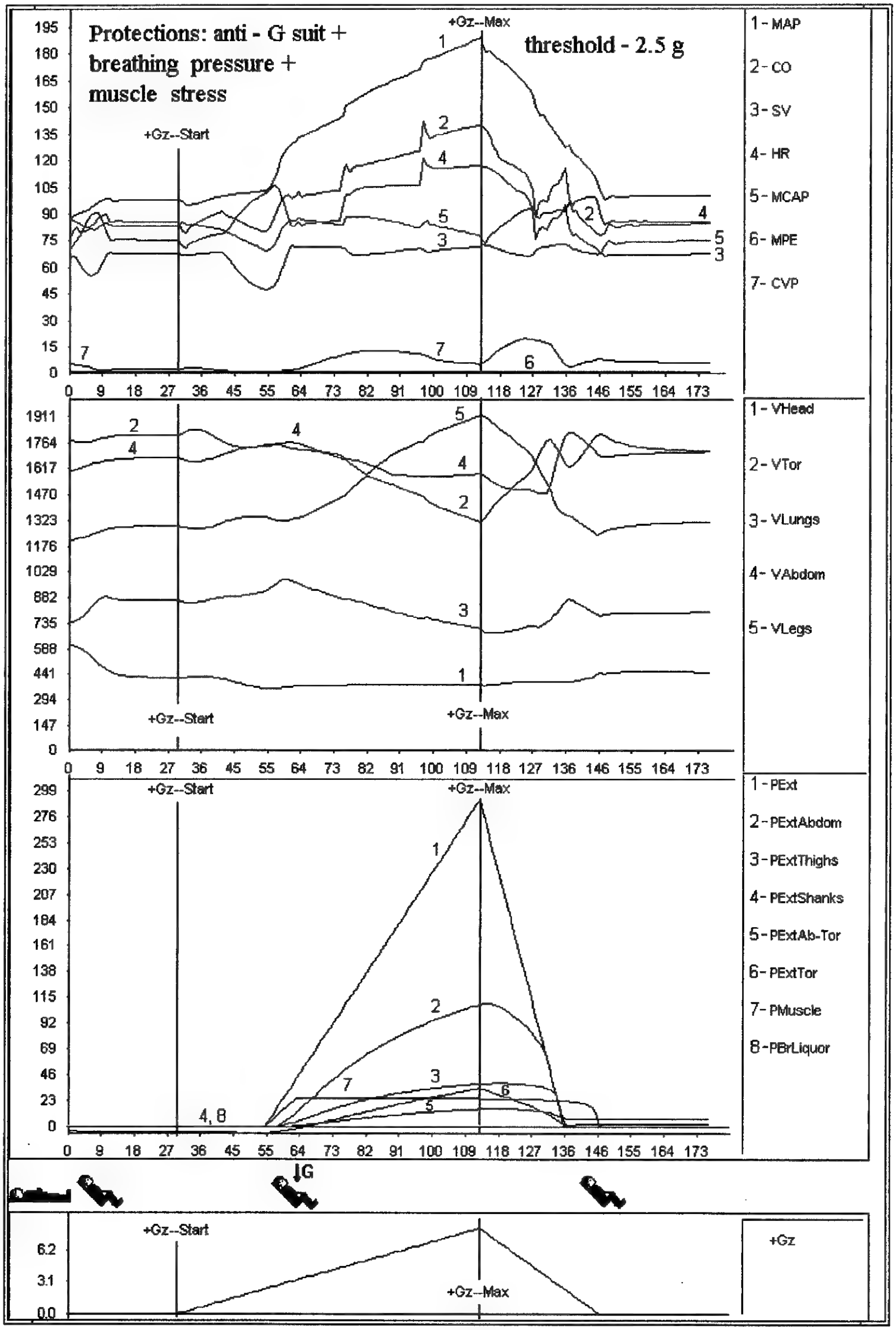


Fig.7. Dynamics of Main Control Parameters During Computer Experiments under Full Protections

For modelling of muscle stress we use the following:

$$P_m == \begin{cases} 0, & g \le g_m^{th} \\ A \cdot P_m^{max} \cdot \left(g - g_m^{th}\right), & g_m^{th} < g \le P^{max} \\ P_m^{max}, & g > P^{max} \end{cases}$$

For modelling hemodynamics effects of breathing pressure increase we assume that the intrapleural pressure Pp increases linear beginning from some +Gz-threshold level:

$$P_p = P_{P_o} - \alpha_{BP} \cdot \left(g - g_{BP}^{th}\right)$$

6. SIMULATION EXPERIMENTS

Our basic hemodynamics model is tuned on abstract healthy man with height 175 cm and weight 75 kg. The summary blood volume is 5500 ml.

The main simulation experiments include following standard procedures. In our model steady-state hemodynamics regime for specified input parameters is reached during first 20s. After that, the program provides changing of human body position from clinstatic to sitting pose with specified angles of aviation stall . When hemodynamics stabilizes, +Gz acceleration begins to grow. It grows until the value of mean pressure on level of eyes' artery becomes lower than 15,0mm Hg. If this happened, the program stops the regime of acceleration with the appropriate message and starts regime of braking. Typical dynamics for control parameters is shown on *fig.6* and *fig.7*..

On *fig.6.* all parameters are represented as 3 group of graphs. The first group, located on top of illustration, includes mean pressures in aortic arch, in carotid sinus and in eyes' artery, heart rate, cardiac output and stroke volume. The group in the middle of illustration consists of summary volumes in head and neck, in thoracic and abdominal cavities, in legs and lungs. The CIT gives us possibility to extend easily this list of output parameters and, if we need, to analyze internal principles of summary volumes. The full list is shown on *fig.5*. The third group of graphs consists of curves of external pressures. We can control the pump pressure and at the same time analyze dynamical transmission pressures characteristics from each section of anti-G-trousers to depth of vessels' location. In the lower part of *fig.4.* the graph of acceleration dynamics is represented.

7. RESUME

Although, one regime of +Gz accelerations is described in the paper, the proposed models, software and CIT are usable both for +Gz accelerations with gradient 1-2 g/s and for other situations. They include postural changes, applications of local negative or positive pressures on different body parts for supine, sitting and erect positions, under weightlessness and water immersion. For almost all situations we have acceptable results for solving some actual problems in aviation and space medicine. Therefore we suppose, that our models and software should be useful for wide applications in airspace physiology and medicine.

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EVALUATION OF FIRST-YEAR PILOT CADET ENDURANCE TRAINING IN THE HELLENIC AIR FORCE ACADEMY.

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1. SUMMARY
The selection and evaluation of physical training proceedures is achieved by ergophysiology and the study of muscle function enzymes.

In our study we have evaluated changes of serum muscle enzymes, Alanine and Aspartate Aminotransferases, Creatine Kinase, Lactate Dehydrogenase and Lactate, in conjunction with changes of heart rate during military endurance training, as indices of muscular and cardiovascular strain.

We evaluated three sets of measurements, one at the beginning of their training, a second after a month of adaptation period, just before the exercises which were performed specifically for the study, and a third by the end of them.

The exercises consisted of the standartized military training protocol and, for comparison, the 1.5 Mile Run Test and an anaerobic one.

Data analysis showed that at the beginning of the endurance training, energy is supplied insufficiently by phosphate Creatine stored in the muscles and by anaerobic glycolysis. After an adaptation period, the muscular strain/energy supply imbalance is compensated by the improvement of the aerobic glycolytic pathway, equally for all individuals.

During intensive physical activity, serum concentration of CK and LDH exceeds by far the normal range and therefore their diagnostic evaluation should be considered with caution.

A better scheduled program of endurance training, at the beginning of training, followed by increased aerobic versus anaerobic exercise and increased carbohydrates intake, might improve pilot cadet fitness.

The influence of intense physical activity on cardiac rate needs further study, specifically if applied in the flight proceedure.

2. INTRODUCTION
The early phase of military life, following the recruitment of new cadets in a military academy, is characterized by a psychosomatic adaptation to the hard military environment.

In addition, the specifically scheduled physical training of pilots, toward improving their anaerobic capacity and endurance performance in the tentative conditions of a flight, have been well documented a long time ago.

Currently, knowledge, proved by the exercise science research and the study of muscle metabolic markers, is employed for the selection of athletes and their training program.(Ref 1)

Studies concerning the evaluation of military physical endurance training, as well as pilot flight physical fitness program, are not well known.

Our study aimed at the evaluation of the standardized and applied pilot cadet military endurance training in the Hellenic Air Force, through changes of their blood muscle enzymes and cardiac rate which were used as indices of muscular and cardiovascular strain. For comparison purposes we employed similar data for already known and standardized, aerobic (1.5 Mile run test) and anaerobic exercises, which were performed in parallel.

Results and subsequent changes may influence the improvement of pilot training programs and fitness.

3. SUBJECTS AND METHODS
3.1 Subjects.
The population under study (38 in total) consisted of 3 randomly selected groups of 9, 14 and 15 new pilot cadets, who participated in the standard military training protocol, a standartized aerobic exercise and a standartized anaerobic exercise, respectively (see below).

Subject height, weight and skinfold thickness were additionally measured for statistical purposes.

3.2 Procedures.
We evaluated three sets of data, one (a) for reference data in the first days of entry into the Academy, just before starting daily training and two others, considered the under study data, following a 30 day adaptation period, one (b) just before and one (c) within 4' following the end of the aforementioned exercises.

The applied military endurance training for the new cadets was a successively performed combination of gymnastics, short duration running and exercises with a 5 Kg rifle, lasting 1-2 hours with short intervals. For our study we kept escalating the time of training, so that the time of participation of every trainee was

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increased by 10' (i.e. 10', 20'...up to 90'). All subjects started together and at the end of eachone's time blood samples were taken and heart rate was recorded.

The aerobic exercise consisted of a 2.400 meter run that was attempted in a 400 meter track of an open stadium.

The anaerobic exercise was a 270 meter race, with reciprocal runs in a 40 meters straight track of a closed gymnasium.

3.3 Biochemical analysis

We measured serum Alanine and Aspartate Aminotransferases (ALT, AST), Lactate Dehydrogenase (LDH), Creatine Kinase (CK) and plasma Lactate (LA).

Blood samples were drawn 2' before and within 4' after the exercise, as indicated, and sera/plasma were assayed within 3 days after collection, while kept in -20 ^{0}C.

For Lactate we used Fthuorate EDTA plasma separated within 30' from blood.

We assayed samples in a Dimension Dupont analyzer and, for Lactate, in a Gilford 300 T photometer with Boehringer Manheim reagents following the manufacturers' instructions. Measurements were within acceptable limits of external (Murex Quality Assessment Programme and internal (CV< 4%) quality control restrictions.

3.4. Heart rate analysis.

The individual heart rate changes during the exercises were recorded by Holter prolonged monitoring ECG devices (OXFORD, MEDILOG) worn by each participant throughout the exercise.

The normal, maximum, and final heart rate were recorded 2' before, during and 2' after the end of an exercise.

3.5. Statistics

For statistics we employed the paired t-test for comparison of means, the Pearson correlation coefficient for parametric correlation's, the Wilcoxon signed rank test for paired samples and Spearman rank correlation coefficient for non parametrics.

4. RESULTS

Changes in measurements of serum muscle enzymes of new pilot cadets, between the early days of their military endurance training and after a month of adaptation, are shown in table 1.

Table 1. Serum concentrations x(SD) of muscle enzymes in new pilot cadets, at the early days of their endurance training (a) and after a month of adaptation period(b)

set	#	AST	ALT	CK	LDH	LA
a	38	35(11)	41(15)	342(151)	536(155)	1(0.2)
b	38	21 (8)	22(16)	303(131)	356 (59)	nm
norm. range		5-40	5-40	10-195	120-230	0.8-2.4

values in U/L, for Lactate mmol/L , nm =not measured

There is a remarkable increase, beyond the normal range, of mean values of CK (342 U/L) and LDH (536 U/L) connected with increased values of SD, i.e. heterogeneity in way of enzymatic response, (151, 155) respectively. It is evident that the 30 day adaptation period, while training, resulted in a reduction of the previously increased values, specifically LDH (356 U/L).

Lactate was found within the normal range before the beginning of the training procedure.

Population characteristics are indicated in table 2. All subjects had similar height and skinfold thickness, the later reflecting to a similar subcutaneous fat distribution, but there was a statistically significant increase in weight moving from aerobic to the anaerobic and then to the military group, attributable to a better developed muscular system.

Table 2. Anthropometric features of the population groups under study.

exercise	#	W(Kg)	H(mm)	TH(mm)
military	9	76.9	178	11.3
aerobic	14	69.2	175	11.7
anaerobic	15	74.5	178	10.7

W=weight, H=height, TH=skinfold thickness

Study of muscle enzyme changes, pertaining to the body muscular structure, between (a) and (b) measurements, showed that 1) the heavier the body (military exercise group), the higher the increase in CK values (450 U/L), (table 3) and 2) the adaptation period resulted in a reduction of values down to a specific level equal in all cases and independent of body weight. Noteworthy is the decrease in SD in LDH measurements, among groups, which settled down from 157, 160, 141 to 52, 63, 62 respectively.

Table 3. The distribution of serum enzymes concentration x(SD) in the groups under study, referred to the early days (set a) and after an adaptation period (set b) measurements (see the text).

exercise	#	AST	ALT	CK	LDH	LA
			set (a)			
military	9	37(13)	45(23)	450(190)	576(141)	1(.3)
aerobic	14	31(8)	38(8)	282(96)	532(157)	1(.2)
anaerobic	15	37(11)	40(14)	333(137)	519(160)	1(.2)
			set (b)			
military	9	20(9)	26(8)	313(181)	381(62)	nm
aerobic	14	9(9)	23(19)	273(101)	348(52)	nm
anaerobic	15	21(7)	19(9)	326(124)	349(63)	nm
norm. range		5-40	5-40	10-195	120-230	0.8-2.4

values in U/L, for Lactate mmol/L, nm = not measured

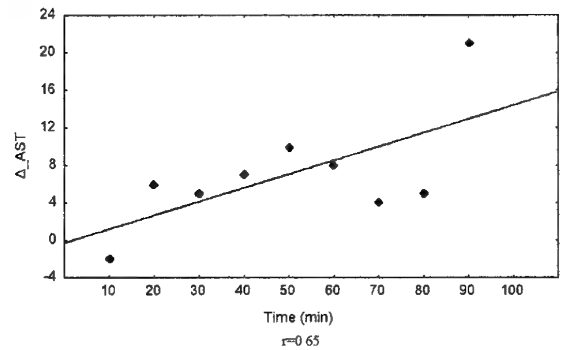
Pre(b) and post(c) exercise measurements are shown in table 4, where it seems that in all enzymes tested there was a similar increase in serum, among groups, which didn't exceed what was found in the early days (a). In all (c) measurements serum Lactate was in very high concentrations.

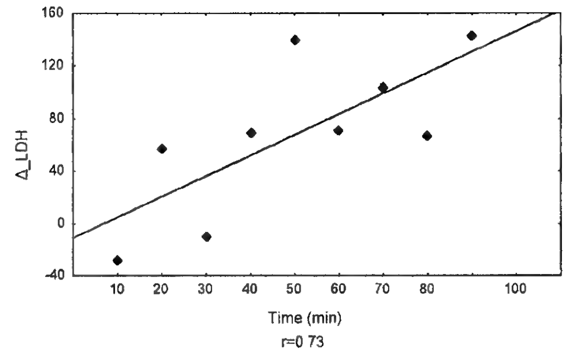
Table 4. Pre/post (b/c) training exercise measurements x(SD).

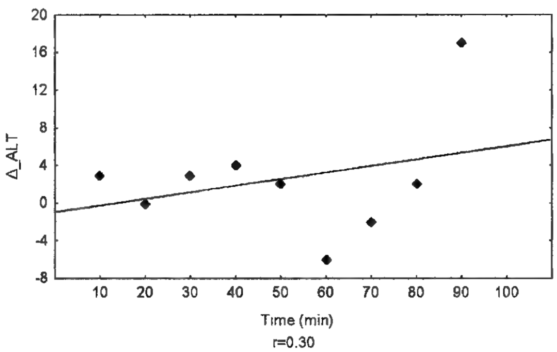
exercise	n	AST	ALT	CK	LDH	LA
military	9	21/28	27/29	313/412	381/449	nm /9.7
aerobic	14	20/23	23/25	273/306	348/397	nm /11.9
anaerobic	15	22/24	19/22	326/352	349/385	nm / 9.7
normal range		5-40	5-40	10-195	120-230	0.8-2.4

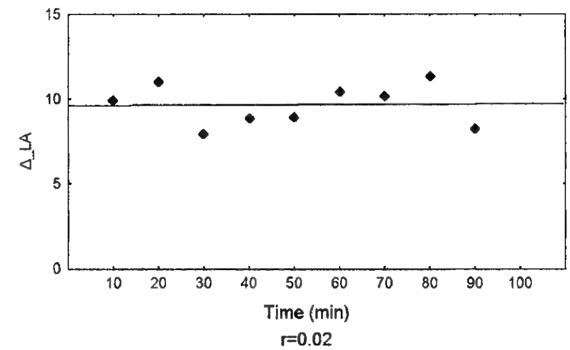
values in U/L, for Lactate mmol/L

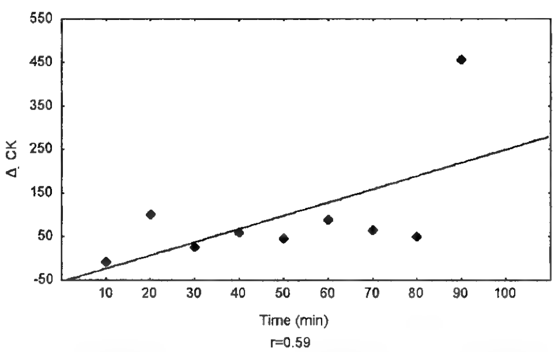
Concerning the initial fitness of participants, they performed the 1.5 Mile Run Test (aerobic exercise) in 10' 5" (mean time) which corresponds to the good fitness category (9' 4" - 10' 48").











Δ_enzyme = the difference of post/pre measurements of enzymes in U/L and for LA in mmol/L.
time = the time of individual participation.

Figure 1. Regression analysis of duration and post/pre military exercise measurements.

Regression analysis of post/pre results in military endurance training are shown in figure 1, along with deduced Pearson correlation coefficients.

The heart rate imbalance, during exercises, is outlined in table 5. Taken into consideration the range of 170-190 heartbeats/min for the age of 18-19, three individuals exceeded their upper limit during the exercise while two others have had episodes of premature ventricular contractions and sinus tachycardia without clinical significance.

Table 5. The heart rate imbalance beat/1', x(SD) during the exercises under study, recorded by Holter prolonged monitoring ECG.

exercise	#	2' before	max.	2' after
military	9	129(29)	178(22)	129(28)
aerobic	14	96(10)	188(11)	150(25)
anaerobic	15	111(14)	163(25)	126(19)

5. DISCUSSION

The energy supply of muscle metabolism through the formation of ATP, is mostly provided by the following biochemical pathways: 1) the aerobic or anaerobic glycolysis 2) the oxidative phosphorylation 3) the breakdown of creatine phosphate (phosphagens) and 4) the pathway of adenylate kinase.

The temporally predominance and the intensity of activation of either one of the pathways, depends on certain factors, as follows:

-The construction of muscles under contraction, (for contraction of long skeletal muscles energy is supplied by oxidative phosphorylation while for short skeletal muscles energy is supplied by anaerobic glycolysis).

-The duration of contraction (for prolonged contraction, ATP is provided by oxidative phosphorylation).

-The food intake (glucose deficiency results in ineffective activation of glycolytic pathway).

-The degree of body fitness (modestly exercised muscles tend to take energy by anaerobic glycolysis). (Ref 2,3)

In our data of the early military training days, the extended increase of CK and LDH expresses the demand for fast supply of energy through the stored Phosphated Creatine and then

through the anaerobic glycolytic pathway. These are indicative of insufficiency in oxygen supply, prevalence of short muscle activation (i.e. prevalence of anaerobic type exercises) and deficiency in carbohydrates, given that the anaerobic exercise consumes more glucose for the same work versus the aerobic.(Ref 4)

Therefore, it should be stressed that, for individuals under intense physical activity, biochemical panels including CK or LDH, obtained for diagnostic purposes, have to be considered with caution. Even increased serum CK-MB has been reported after physical activity.(Ref 5)

There was an almost equal degree of enzymatic adaptation leading to better response to the military training after a month, though serum LDH concentration was steadily high. Prolonged high serum LDH in seasonal workers has been attributed to not well ordered work rate and rest time, within the daily and seasonal working routine.(Ref 6, 7)

From the correlation of the increase in serum enzymes and the time of military endurance training there is a significant increase of LDH, after the first 10', and to a lesser extend a CK increase, indicative of the incapability of other pathways to supply energy besides anaerobic glycolysis.

There is a tremendous increase in serum Lactate within the first 10', far beyond the 4 mmol/L that is considered the limit of anaerobic pathway activation. According to Haraiambie and Senser for long duration (24 hours) athletes (swimmers) the energy supply is mainly provided from lipids breakdown through oxidation, after a short period of anaerobic glycolysis. For them, the best of athletes could adapt themselves easily to the oxidative metabolism and have had lower serum Lactate concentration as compared to less qualified athletes. The performance capacity at the 4 mmol/L Lactate limit may cause fatigue syndrome. (Ref 8, 9, 10)

Finally high serum Lactate is encountered in anaerobic type exercise.

The cardiac rate episodes, after physical overtraining, were considered without clinical significance but whether they might appear and effect pilot flight ability is currently under study.

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IMPLICATIONS OF DYNAMIC SOCIOMETRY IN OPTIMIZATION OF MANAGEMENT STRUCTURES OF THE CZECH AIR FORCE

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SUMMARY

The aspects of socio-psychological management are becoming increasingly appreciated in evaluation of social complexes. The management procedures include selection, shaping and training of small social groups as a backbone of any social organization. The performance of these groups greatly depends on socio-psychic atmosphere that is influenced by the quality of communication among individual group members as well as separate levels of management. Psychic tensions as a source of conflict and/or stress are mostly the result of a distorted communication flow. In search of its roots we are usually looking at personality qualities of individual subjects. Yet another ground of socio-psychological disturbance lies in socio-psychological background, e.g. organisation of training or the structure of management.

Dynamic sociometry provides a profound analysis of social relations within small groups as well as among such groups. Using the methods of dynamic sociometry ten management teams with the total of about 1.200 respondents within the organisational structure of the Air Force and Air Defence, Army of the Czech Republic, were evaluated.

Results of practical implications of dynamic sociometry will be presented in greater detail. These implications ratify the specific value of socio-psychic factors in increasing the effectiveness of the Air Force Command.

1. PROBLEM

A detailed analysis of work teams within the Air Force, each base as well as the interactions between the bases and the command post has taken place (Fig. 1). The main subjects of this analysis were the quality of communication flow, mutual relations structure, critical relations and configurations within the system. The analysis should result in management optimizing recommendations. As the procedure has been working at various system levels - starting with the relations between the five bases and the command post, and going on with relations between staff teams (the total number of teams processed reaches 63) and within the teams - it has collected data from as many as 800 persons.

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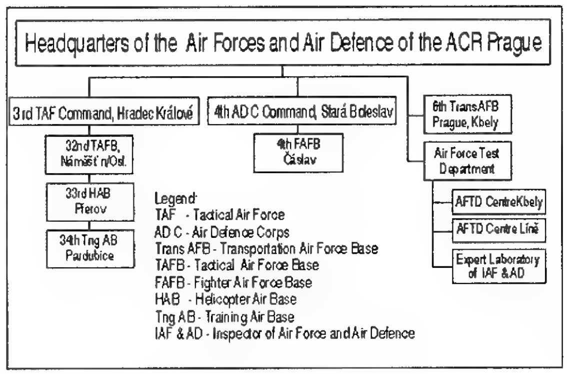

Fig. 1 Formal structure of the air force

2. METHOD

Dynamic sociometry and sociomapping (1, 2), allowing to examine the relations on several levels, have been used to analyze the sample. Data needed for such a broad investigation have been collected through the content analysis of documents and communication, and testing (Tab. 1 a, b, c).

Table 1 a, b, c. Example of data inputs transferred into so called fuzzy models of group.
(One of the domains of sociomapping is the analysis of incomplete and indefinite data)

1 a. TEST OF HARMONIZATION DEGREE								
Person	1	2	3	4	5	6	7	8
1		0,36		0,95				0,42
2	0,24		0,82	0,90				0,58
3	0,52	0,76						
4	0,61				0,45			
5	0,55			0,64				
6	0,91	0,73		0,73				
7	0,58							
8	0,88	0,64	0,73					

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1 b. TEST OF COLOR ASSIGNMENT								
Person	1	2	3	4	5	6	7	8
1		0,7		0,7				0,6
2	0,8		0,9	0,7				0,4
3	0,9	0,9						
4	0,7				0,7	0,6		
5	0,4			0,96		0,2		
6	0,98	0,75		0,95				
7	0,7							
8	0,8	0,7	0,7					

1 c. TEST OF SEMANTIC CHOICES								
Person	1	2	3	4	5	6	7	8
1		0,63		0,63				0,38
2	0,44		0,44	0,38				
3		0,31						
4	0,81				0,63			
5				0,75				
6	0,81	0,56		0,63				
7	0,38							
8	0,19	0,31	0,25					

3. EXAMPLES

Using modified examples the potential of the above mentioned procedures can be presented.

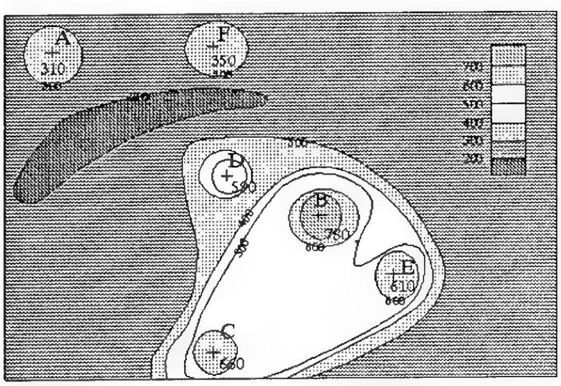

Fig. 2 Sociomaps of groups - analysis No. 1

Analysis No. 1 (Fig. 2) uses data concerning the communication links between several groups. Within the system, expected to be as integrated as possible, the study has shown a certain lack of coherence between some of the groups. Moreover, the real communication ways and levels were compared to the formally given order of the system. The most critical position is held by group A, that should play the role of the local command post and therefore be a tie between the other sections. This role is more or less taken over by group B. Incorrectly integrated group F should be subordinate to group D, which relation is actually nonexistent, instead group F is rather oriented as subordinate to group A.

Recommendation: Group A should either emphasize its communication with groups C and D, or it would be acceptable to formalize the existing communication system by subordinating groups C and D to group B. Group F could then be subordinate to group A. Recommendation of formal changes in subordination is reasonable whenever the corresponding structures indicate similar malfunctions of actual communication. If such a malfunction is found only in one case, then it is a specific feature of that given system that should not be resolved by structure changes but rather by restoring the communication after an analysis of these malfunctions and critical spots. To attain this recovery a comparison to similar working systems should be used. Communication stream study may reveal malfunctioning back ties between army units or blocked communication as a result of disturbed relation between the two units. A detailed examination may divulge determination of inter-group relations by relations between individuals. In this case, the position of group B is also established by the fact that it is the most consistent and best cooperating group of the whole system. That leads to the conclusion that in order to improve the integrity of the whole it would help to increase the integrity within the groups.

Analysis No. 2 (Fig. 3) reflects two states of one work group. First figure shows the group fallen apart into two rather noncooperating fractions. The temporary commander come out of one of the fractions and was not accepted enough by the other fraction. After an experienced associate T entered the team, a thorough integration of both parts had taken place at the same time as the former commander had taken the post of a deputy commander and thus became more acceptable for the fraction that at first was rejecting him, the only ill outcome was the setback in position of person B, that had probably played its role in the separation. It can be assumed that after an eventual departure of person T following a period of stabilization within the group, the group will be overall more integrated, thus more productive, for approaches between members of the former fractions are apparent.

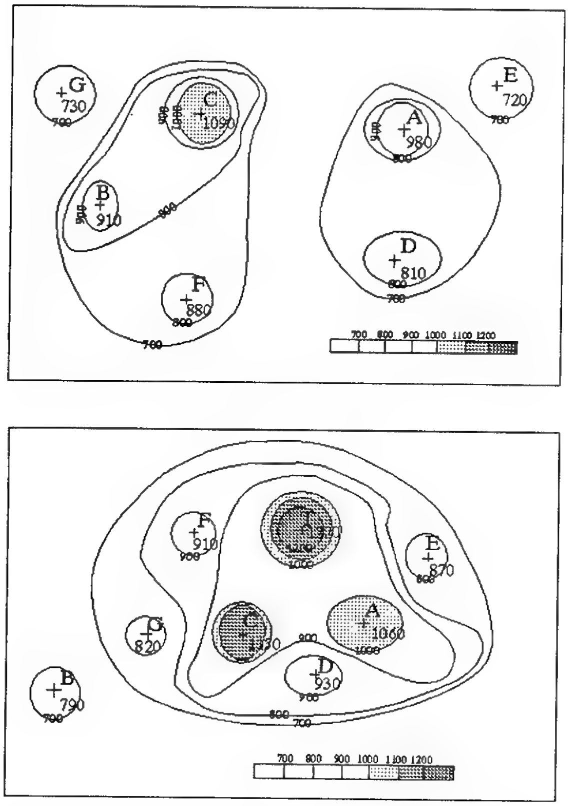

Fig. 3 Sociomaps of work team - analysis No. 2

4. RESULTS

The whole project is still under way having finished the early mapping of the system that has resulted in depicting the current situation oriented towards uncovering any reserves and critical spots within the system. The results have been presented not only at the command post, but relevant data have also reached the units under its command. The analysis results have been followed by appropriate recommendations. It is expected that the whole system will be thoroughly examined over a prolonged period of time to enable a study of the realized changes' effects and further developments.

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TIME HAS COME FOR MANDATORY COMPUTERIZED PSYCHO-NEUROLOGICAL EXAMS IN BOTH MILITARY AND CIVIL AVIATION

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SUMMARY:
Multiple efforts were made in the pre-computational era to prove which were the psycho-neurological characteristics of both: successful and the so called "failing" pilot. Psychomotor skills were difficult to examine until computers became chip and little. **Material and Methods:** "Multiple Stimuli Generator" (MSG) is a 360 Kb. computer program which runs in any PC with two "mouses" attached to COM1 and COM2 ports. We tested 512 civilian, police and military student pilots (SP) before they begun their Undergraduate Pilot Courses, and 54 Commercial students pilots. Results were confronted with Instructor Pilots (IP) rankings of their students. Multiple Linear Regression and Kruskal Wallis statistical tests were applied. **Results:** Estimated model of the regression equation took 5 out of the 9 MSG variables. Difference among the four IP criteria were highly significant. Medians of each four groups were calculated using the regression equation and applied to rearrange the sample studied. All but 4 subject were coherently distributed into the sub-groups that medians had determined. **Conclusion:** Seven SP were grounded and two helicopter pilot killed themselves in Aviation accidents. These 9 subjects were all pre-identified by the MSG as belonging either to the "non-fit-for flying" or "fit-with-reservations" groups. MSG demonstrated so far being an excellent tool in predicting "failing" would be pilots, both in civilian and military milieu.

1. INTRODUCTION:

1.1. In several countries the Civil Aviation Authorities are close related with or managed by the Air Force. That's the situation in Argentina. In this cases civilian student pilots are tested with psycho-neurological tools like their military counterparts, although applying lighter requirements.

1.1.1. Latter in their careers, some military pilots continue flying in airline positions, and some civilian private pilots apply to Air Force Academies. So, differences in selection criteria and methods are a controvertible issue.

1.2. On this subject, there are several issues on witch we agree for sure, but the title itself is controversial. So let me make some introductory remarks to review those facts that are known and widely accepted. Latter on I shall go into the controversial issue.

1.2.1. We surely agree that our main duty as Flight Surgeons and experts in Aviation Medicine, is to perform our service with the highest possible degree of safety, in the public interest.

1.2.2. We also agree that the Flying System works well, but not perfectly. Our social conscience demands a more aggressive approach to aviation safety.

1.2.3. We agree that flying, under certain circumstances, is extremely demanding, that it requires a very high level of cognitive and psychomotor functions, under certain circumstances.

1.2.4. We agree that the Aviation System is becoming continuously even more demanding and that the increasing aviation activity will lead to more accidents even if the accidents' rates remain constant.

1.2.5. I suppose we agree that accident's rate must be decreased, not remain leveled, in the phase of a more complex, demanding and crowded System with more flying activity.

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1.2.6. We agree that human performance failures account for between 60 to 70% of all aviation accidents, and is the major contributor to Undergraduate Pilot Training (UPT) attrition.

1.2.7. **BUT**, (and this is a big BUT) the Human Mind, the responsible for those statistics, is a metaphysical, intangible and non-measurable object, with no right to any decent scientific existence, particularly if one think in it from a narrow empirical epistemological framework.

1.2.8. So, should have anybody the right to prevent anyone to get a pilot license based just on causes that begin with the letters
"p-s-y" (except for psychosis, of "bien entendu")?

1.2.9. On the other hand, have the "p-s-y" disciplines enough scientific seriousness or hart data to claim for themselves the same scientific and prestigious status that "physical" medical disciplines have?

1.2.10. Is it by any mean possible to bypass both, the expert's observational perturbation and the subject dissimulation, dealing with traditional psychological paper and pencil tests or the so called "projective" tests, or the multiple inventories style tests ?

1.2.11. That was the real pre scientific situation till **"cybernetic cavalry"** step into the scene and the human mind became measurable. Fast and little computers allow us now to measure Human Mind functions, skills and performance.

1.2.12. Nowadays psycho-neurological functions (as we call them) are as hart data as blood pressure or cholesterolemia.
We already accept this philosophy for military pilots, because of their strategic importance, their demanding job, the 1 million plus dollars taxpayers must afford for each one of them, and the skyrocketing costs of military aircrafts.
But, civilian student pilots have a very different treatment, and **this is the** controversial issue here.

1.2.13. From the previously outlined standpoint, we propose to fight against the perverse myth of most Civilian Instructor Pilots that deny that some individuals should not fly.
The other side of this coin, is that Civilian Flying Instruction is no more than a business, for these instructors.
In that sense, we threw away paper and pencil tests and took the computers.

2. MATERIAL AND METHODS:

2.1. So, thinking in massive screening we developed several computer based tests. The "Multiple Stimuli Generator" (MSG).

2.2. MSG measures psychomotor skills, divided attention, rapidity and accuracy to learn unusual controlled hand movements, and operational criterion in high stressed context.

2.3. MSG can be run **in any compatible Personal Computer** (PC), with a single specification: it must have ***two mice*** plugged to COM1 and COM2 serial ports.

2.3. After asking for testee data entry and offering a demo of 30 seconds to appreciate mice sensitivity, the test begins with a circular red target (A) that moves randomly throughout a big rectangle and is intended to be "chased" (pursuit tracking) with a green plus sign (B) whose movements are controlled by the right-hand mouse (Figure 1).

2.3.1. Another target, a blue triangle (C) moves just in a vertical direction, also randomly, up and down, intended to be "matched" with a green arrow (D) controlled by the left-hand mouse. This left-hand mouse has a peculiarity, it works upside-down, when you go forward with the mouse, the green arrow goes down, and viceversa, so you must learn fast an unusual movement.

2.3.2. The computer will count **25 times per second** the distance between targets and its respective green cursors and will calculate their average minute by minute. So we have here 10 numeric data, five for each mouse, which will give rise to the first composite variable.

2.3.3. The Stage II goes on immediately with its explanation on screen. Now, while performing the same tasks as above, the subject should be alert to the lightening of four little rectangles (E) in the

screen's four angles. This lights remain on through 4 seconds, waiting for the "click" of the right button of the right mouse, **i.e.**: Outer buttons for upper lights, inner buttons for bottom lights.

2.3.4. The computer will count how often the testee did well, wrong or omitted a "click" at all. Of course, also will measure, as in the first stage, the performance with the two targets. The average of the latest will be the second Composite variable.

2.3.5. The performance with bottoms are also counted: amount of accuracies, errors and omissions and the reaction time.

2.3.6. After five exhausting minutes, finally comes the Stage III. The computer displays on screen the instructions again. Besides the previous tasks, the testee should now use his/her **cerebral prefrontal cortex** to make 40 mathematical calculi, which will be displayed in a little rectangle at the central upper part of the screen (F). The result is always a single digit and should be input using the numerical pad. These are the last five minutes.
In this stage, the computer will count the same as above and also the accuracies, errors, omissions and the reaction times for calculi.

2.3.7. The composite variables generated by the test and considered for statistical calculi, are drawn in a histogram that can be seen in the Figure 2.

2.4. The MSG, was given to 512 Student Pilots (SPs) before Undergraduate Pilot Training, and 54 Commercial Student Pilots.

2.5. The validation criterion was the **operational classification** given to these Student Pilots (SP) by consensus, by their Instructor Pilots.

2.6. The IP proposed four categories to qualify skills and "safety" of their SPs: "Above Standard" (Criterion 4), "Standard" Criterion 3), "Below Standard" (Criterion 2) and "Substandard" (Criterion 1).

2.7. In this report we will include just the 304 civilian SPs.

Some Military and Police helicopter pilot results will be shown and discussed briefly later on.

2.8. Multiple linear regression analysis was used to obtain the estimated regression coefficients, and the estimated model equation. Kruskal-Wallis analysis of variance was used to verify the hypothesis that the different IP Criteria belong to the same sample.

3. RESULTS:

3.1. As can be seen in Table I, the composite variables: 2M1, 2M2, 2M3, LM, 4B3, C3, OmB, OmC y STIII present a considerable dispersion, due to differences in subjects' psychomotor skills, and "operational criteria".

3.2. For the first multiple linear regression model, "I.P. CRITERIA" was the dependent variables and the mentioned composite variables were the independents.

3.3. In Table II the final model of the estimated coefficients for each independent variable are shown. These coefficients will give rice to the regression equation.

3.4. Secondly, several mathematical models were proved, and the MEDIANS of each group were the best predicting variables.
Their values for each "CRITERION" were: 2.14, 2.67, 3.16 and 3.36. (Table III).

3.5. Applying the Regression Equation to the sample again, with the MEDIANS OF THE I.P. CRITERIA as dependent variables, the distribution of the subjects resulted as shown in the Table IV.

3.6. With this stratification subjects distribute themselves in a satisfactory way, except 2 false negatives and 2 false positives, as can be seen in Figure 3.

3.7. In Figure 4 the medians obtained by the Regression Equation for the first three criteria are drawn, so the sample became stratified into 4 groups. The importance of this stratification is discussed bellow.

4. DISCUSSION:

4.1. The objective of this study was to analyze the possibility of detecting "ab-initio", those SPs that have high probabilities for failing in the training course, or what is worst, may become "unsafe" private pilots.

4.2. We may summarize saying that those subjects' performance that fall bellow the MEDIAN of the I.P. CRITERION 1 may be considered NOT FIT FOR FLYING

4.3. In the second sector, between 2.14 y 2.67 are the subjects who have moderate psychomotor difficulties. These SPs could be considered "FIT FOR FLYING w/RESERVATIONS" or Ad-Referendum from the opinion of their IPs.

4.4. In the third sector, above 2.67 we have no surprises. No "Substandard" SP's are included, and all "Above Standard" SPs are at the right side of this cut-line (except the false negatives and the false positives).

4.5. These SPs may be considered FIT FOR FLYING for standard licenses for planes, helicopters, gliders, ULM, etc.

4.6. Finally, above the MEDIAN of the 3rd Criterion (3.16 in Figure 4), are the finest pilots, with excellent psychomotoric conditions.

4.7. This sector has no specific utility in civilian milieu, but would be the locus for "ab-initio" selection of fighter pilots in the military aviation. Data are insufficient for the moment, but some preliminary results will be shown later on.

4.8. In this research we found 2 false positive and 2 false negative. They are the SPs that seem to be "dislocated" in Table IV. It may be said that, in one extreme, SPs with excellent psychomotoric skills may fail in the real flight because of subconscious fears, airsickness, etc.

4.9. In the other end of this *continuum*, the two SPs that where classified by their IPs as superb, and performed very poorly in the MSG, have several possible explanations.

4.9.1. Perhaps, the day the test was given to them, they were under any drug effect, fatigue, anxious for the situation, distracted, perhaps they were in a hurry and wanted to finish as soon as possible, or simply they did not pay enough attention to the test since they were told (as any other) that the test was experimental and had no power to disqualify them.

4.10. The ideal is that every subject be "equidistant" from the test, but it is not always possible.

4.11. Finally, it must be remembered that psychomotor tests measure psychomotor skills and not flying skills. To state in the laboratory, "ab-initio", the ability to fly safely, remains a scientific challenge, whose first steps are been done.

5. CONCLUSION:

5.1. Standards in the empirical branches of Aviation Medicine are well established. More than that, the FAA already gave 2000 plus waivers for coronary bypassed pilots, pilots with coronarioplastic surgery, and pilots who suffered Myocardial infarction.

5.2. This is the result of serious studies that demonstrated that "flying unsafety" is not allocated in those sick arteries.
We now know that "Flying unsafety" is allocated **one foot higher** those arteries.

5.3. As an example of what can be achieved prospectively with this instrument in other fields, here you have the "MSG profiles" of three military SP that were grounded the last year in their UPT. One of them after 70 flight training hours. A lot of money wasted. Figure 5.

5.4. In the case of Police Helicopter SP, two of this group killed themselves in separate accidents due to pilot error. In Figure 6 their profiles can be seen.

5.5. So, computerized psycho-neurological tests come to fill the abyss between hart medical disciplines and soft ones, like "Aviation Psychology" and "Aviation Psychiatry"; and to redeem us for our previous "Complex of Inferiority".

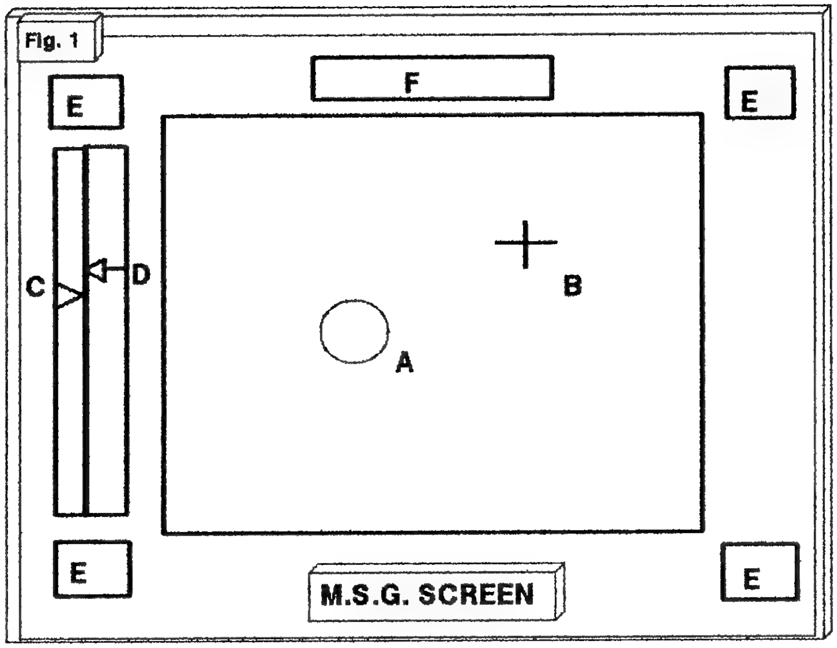
Fig. 1
E
F
E
C
D
B
A
E
M.S.G. SCREEN
E

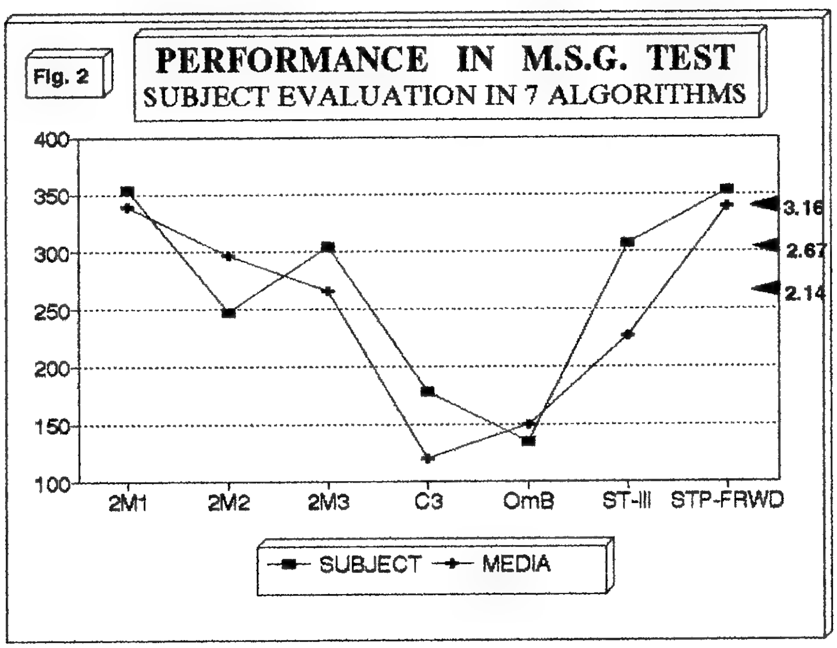
Fig. 2
PERFORMANCE IN M.S.G. TEST
SUBJECT EVALUATION IN 7 ALGORITHMS
400
350
300
250
200
150
100
2M1
2M2
2M3
C3
OmB
ST-III
STP-FRWD
3.16
2.67
2.14
SUBJECT
MEDIA

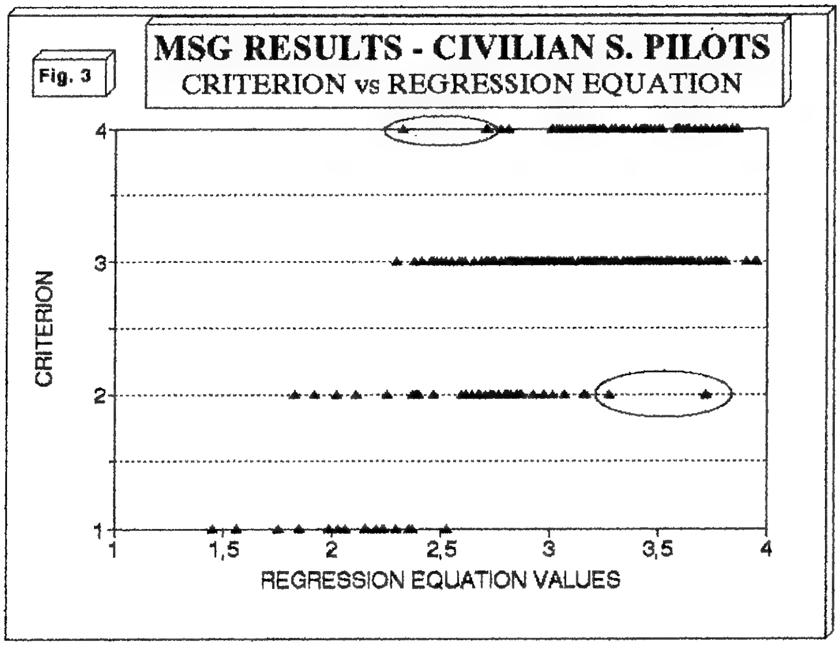
Fig. 3
MSG RESULTS - CIVILIAN S. PILOTS
CRITERION vs REGRESSION EQUATION
CRITERION
1
2
3
4
1
1,5
2
2,5
3
3,5
4
REGRESSION EQUATION VALUES

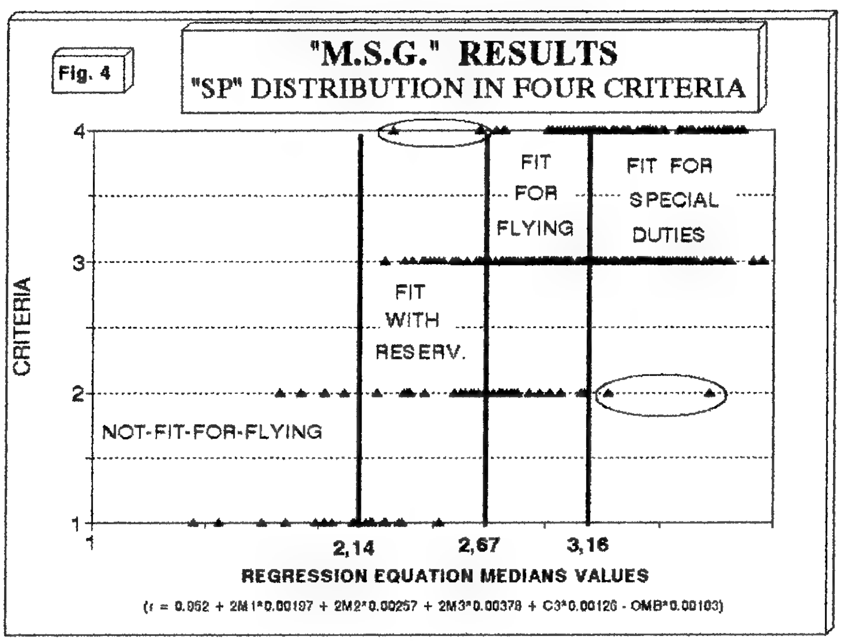
Fig. 4
"M.S.G." RESULTS
"SP" DISTRIBUTION IN FOUR CRITERIA
CRITERIA
1
2
3
4
FIT FOR FLYING
FIT FOR SPECIAL DUTIES
FIT WITH RESERV.
NOT-FIT-FOR-FLYING
1
2,14
2,67
3,16
REGRESSION EQUATION MEDIANS VALUES
(r = 0.952 + 2M1*0.00197 + 2M2*0.00257 + 2M3*0.00378 + C3*0.00126 - OMB*0.00103)

TABLE I:

COMPOSIT VARIABLES VALUES

V. NAME	MEAN	MIN.	MAX.
2M1	327.705	66.81	304.17
2M2	253.145	3.8	358.95
2M3	243.105	-62.570	353.04
LM	179.44	-124.22	429.78
4B3	98.01	1.37	335.79
C3	128.41	10.79	429.18
OMB	156.25	-233.50	295
OMC	160	10	200
ST-III	150.42	29.79	253.33

TABLE II:

MULTIPLE REGRESSION MODEL. ESTIMATED COEFFICIENTS FOR INDEPENDENT VARIABLES

INDEP. VARIABLES	REGRESSION COEFF.	STANDARD ERROR	Z	P	MEAN
2M1	.0019	.000829	2.385	0.018	318.0
2M2	.0026	.000575	4.651	0.000	239.6
2M3	.0037	.000535	7.082	0.000	225.3
C3	.0012	.000540	2.334	0.020	174.5
OMB	-.0010	.000532	-1.948	0.052	152.1
CONST.	.9528	.258641	3.684	0.000	1

TABLE III:

REGRESSION EQUATION DISTRIBUTION ACCORDING TO "CRITERIA"

CRIT	# OBS	MEAN	VARI-ANCE	S.D.	MEDIAN	MIN.	MAX.
1	15	2.06	0.08	0.29	2.14	1.43	2.50
2	36	2.62	0.16	0.40	2.67	1.80	3.66
3	183	3.14	0.11	0.34	3.16	2.27	3.89
4	70	3.32	0.10	0.32	3.37	2.29	3.80

P = 0.0000

TABLA IV:

REGRESSION EQUATION DISTRIBUTION FOLLOWING INSTRUCTOR PILOTS "CRITERIA".

	MEDIANS				
CRITERIA	2.14	2.67	3.16	3.36	**TOTAL**
1	**8** 53% 61%	**7** 47% 18%			**15** 5%
2	**5** 14% 38%	**13** 36% 33%	**16** 44% 15%	**2 *** 6% 1%	**36** 12%
3		**17** 9% 44%	**70** 38% 66%	**96** 52% 65%	**183** 60%
4		**2 *** 3% 5%	**20** 29% 19%	**48** 69% 32%	**70** 23%
TOTAL	**13** 4%	**39** 13%	**106** 35%	**146** 49%	**304**

* THESE FOUR CASES ARE FALSE POSITIVE AND FALSE NEGATIVE. SEE TEXT.

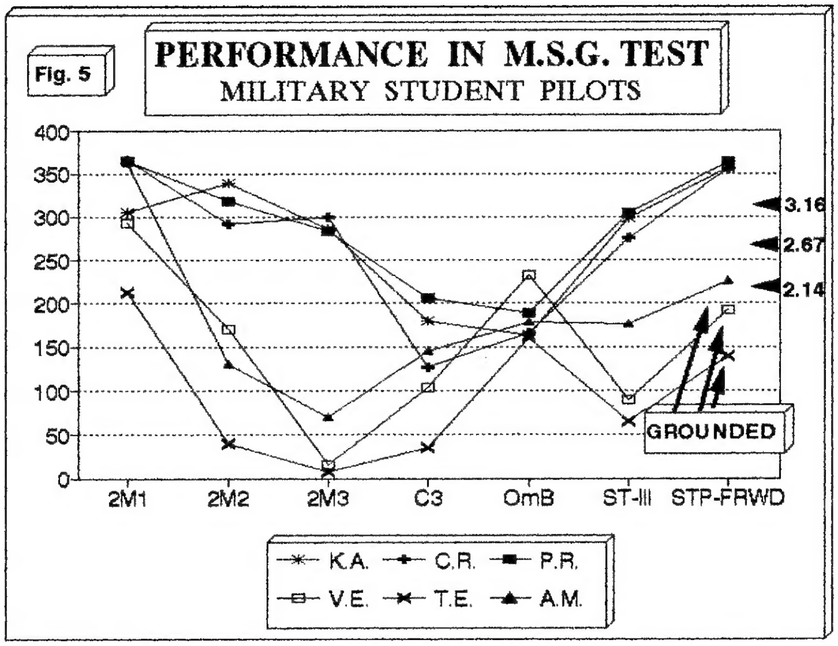
Fig. 5
PERFORMANCE IN M.S.G. TEST
MILITARY STUDENT PILOTS
400
350
300
250
200
150
100
50
0
2M1
2M2
2M3
C3
OmB
ST-III
STP-FRWD
3.16
2.67
2.14
GROUNDED
K.A.
C.R.
P.R.
V.E.
T.E.
A.M.

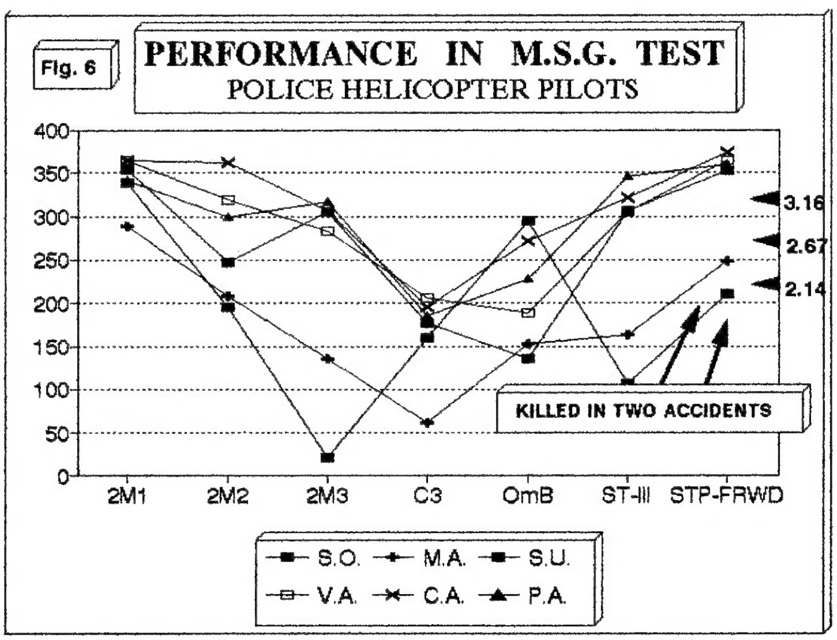
Fig. 6
PERFORMANCE IN M.S.G. TEST
POLICE HELICOPTER PILOTS
400
350
300
250
200
150
100
50
0
2M1
2M2
2M3
C3
OmB
ST-III
STP-FRWD
3.16
2.67
2.14
KILLED IN TWO ACCIDENTS
S.O.
M.A.
S.U.
V.A.
C.A.
P.A.

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Acceleration tolerance
Tolerances (physiology)
Gravity
Aerospace medicine
Centrifuges
Cockpits
Resource management
Cognition
Personality tests
Psychomotor tests
Intelligence tests

14. Abstract

These proceedings include the Technical Evaluation Report, Keynote Address, Paper Presentations, and Poster Display Presentations of the Symposium sponsored by the AGARD Aerospace Medical Panel and held at the Ministry of Defence, Prague, Czech Republic, 28-31 May 1996.

Over the last few decades, aircraft and air operations have become more sophisticated. Technological innovations have resulted in higher-performance, more-complex weapons systems. That increased performance and complexity have placed greater physical and psychological demands upon aviators. Refinement of materiel and improvements in selection and training technologies have enabled aviator selection and training processes to evolve. The purpose of this Symposium was to unite military and civilian experts in the field of selection and training. The papers addressed aviator selection and training, including (a) human abilities measurement;
(b) anthropometric accommodation; (c) gender differences; (d) crew resource management;
(e) flight simulators; (f) spatial disorientation; (g) cost effectiveness; (h) centrifuge training; and g-tolerance.

These proceedings will be of interest to those concerned with selection criteria, progression in selection techniques, training processes, physiological training, and facility advances in aviation. Interaction of medical, physiological, cognitive, psychomotor, and personality factors in the selection process are highlighted.

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